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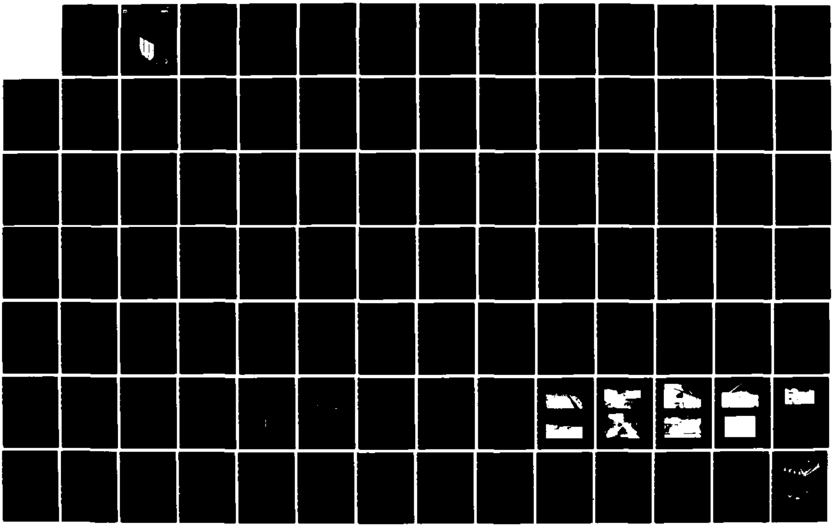

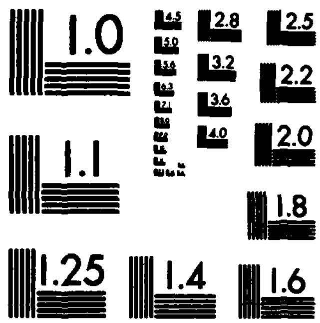

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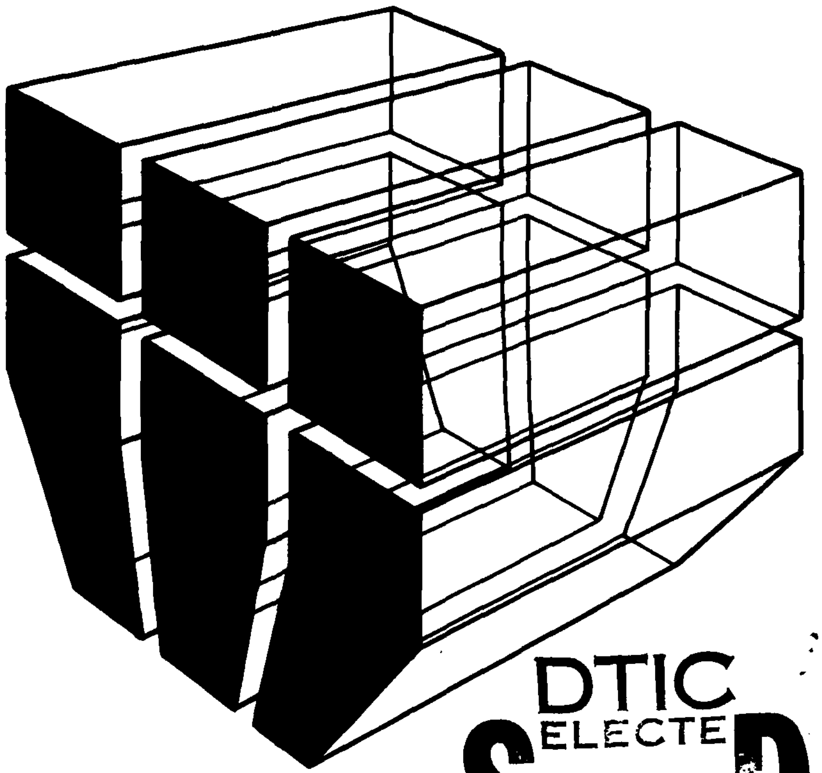
US Army Corps of Engineers
Construction Engineering Research Laboratory

TECHNICAL REPORT N-182
August 1984

UPGRADING ARMY SEWAGE TREATMENT PLANT TRICKLING FILTERS WITH SYNTHETIC MEDIA



by
Calvin P. C. Poon
Richard J. Scholze
John T. Bandy
Ed D. Smith

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This report evaluates synthetic media as an appropriate method for upgrading Army wastewater treatment plants and provides guidance on selecting the appropriate type of media, design procedures, costs, and operations and maintenance.

The Army owns and operates more than 100 Army wastewater treatment plants in the U.S., ~~the United States, of which~~ more than half involve some type of trickling-filter system. ~~However,~~ many of these plants, which represent a substantial

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capital investment, are aging and ~~are~~ showing ~~the~~ associated signs of physical deterioration. ~~As a result,~~ new plants must be built or existing ones upgraded or renovated. ~~While each installation's needs are site-specific,~~ renovation is often more cost-effective than new construction.

On the basis of this research, plastic media ~~were found to~~ have several advantages over conventional filters: low energy consumption, reliable performance, resistance to hydraulic and organic shockloads, simple operating procedures, effective land use, and reduction in sludge bulking problems. They also provide other capabilities, including roughing, secondary treatment, and nitrification, thus giving partial or complete wastewater treatment, depending on an installation's needs.

Estimates of the costs of new filter construction showed that costs increased with increasing media depth for a given filter diameter and that pumping facility costs increase rapidly as the filter diameter decreases. For filter renovation, the amount of work and cost varies ~~among~~ plants, depending on how much work is needed to achieve upgrade.

The type of treatment technology used at Army facilities depends on the characteristics of the application. In determining the circumstances under which synthetic-media trickling filters should be chosen over other alternatives, the major decision factors are cost-effectiveness, performance reliability, energy requirements, operating skill, and land needs. These factors should be weighed in terms of the needs of the individual installation. In general, plastic-media filters should be selected when:

1. Existing rock filters need renovation.

2. Partial removal of ~~BOD5~~ is needed preceding another secondary treatment unit.

3. The most important criterion is minimizing energy use.

FOREWORD

This research was conducted for the Directorate of Engineering and Construction, Office of the Chief of Engineers (OCE), under Project 4A762720A896, "Environmental Quality Technology"; Task B, "Source Reduction Control and Treatment"; Work Unit 043, "Design and Operation for Upgrading Wastewater Treatment Plants." The work was performed by the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (CERL). The applicable QCR is 6.27.20A. The OCE Technical Monitor was Walter Medding, DAEN-ECE-G. Dr. R. K. Jain is Chief of EN.

COL Paul J. Theuer is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

The Army owns more than 100 wastewater treatment plants, of which more than half use trickling filters for secondary treatment. Trickling filters are easy to operate, reliable treatment systems which usually meet National Pollutant Discharge Elimination System (NPDES) permit standards and are appropriately sized for use at installations. However, many of these units are aging and are showing evidence of attendant physical deterioration. Also, stricter environmental regulations and regional population increases which add to the system's load have supplied the impetus for renovating, upgrading, or replacing existing wastewater treatment systems.

Trickling systems are the backbone of the Army's wastewater treatment system and will continue to be the most pervasive wastewater treatment method because they are easy to operate, reliable, consume little energy, and represent a large capital investment. A new trend in the wastewater treatment industry which is highly applicable to Army use is replacing rock media with synthetic (plastic) media in trickling filters. The use of plastic media for upgrade has several advantages:

1. Borderline permit offenders can be brought into compliance at minimal cost.

2. Plastic media filters can be installed at a much greater depth, which takes advantage of the fact that Biochemical Oxygen Demand (BOD_5) removal is a function of filter depth.

3. Organic and hydraulic loadings can be increased, so overloads can be handled easily.

4. Operation and maintenance of plastic-media trickling filters is essentially the same as for rock trickling filters.

5. New construction can proceed rapidly, since less massive underdrains and retaining walls are needed.

6. New developments, such as the trickling-filter solids contact process, can provide treatment at the highest levels required.

7. Plastic media have a proven track record in Army, municipal, and industrial applications.

To use this technology effectively, the Army needs guidance on selecting plastic media, design, operation, costs, and the applicability of synthetic media, both as an upgrading alternative and for new construction.

Objective

The objectives of this study were (1) to evaluate plastic media as an appropriate upgrade/new construction means of wastewater treatment for the Army, and (2) to provide guidance on selecting, designing, operating, and evaluating synthetic media for trickling filters for installation Directorate of Engineering and Housing personnel, Corps of Engineers District design engineers and reviewers, and architect/engineers.

Approach

Army installation wastewater treatment using trickling filters was surveyed and analyzed. Information from literature review, manufacturers, telephone and letter surveys, and site visits was compiled and analyzed. Based on the analysis, guidance on use of synthetic media in trickling filters was compiled.

Mode of Technology Transfer

It is recommended that information from this investigation be incorporated into Technical Manual (TM) 5-665, Operation and Maintenance of Wastewater Treatment Facilities (January 1982); TM 5-814-3, Domestic Wastewater Treatment (November 1978); and Engineering Manual EM 1110-2-501, Design of Wastewater Treatment Facilities Major Systems (September 1978). An Engineer Technical Note will also be published.

2 WASTEWATER TREATMENT PLANT

Survey Data

In 1979, the U.S. Army Office of the Chief of Engineers surveyed the Army's wastewater treatment facilities in the United States. Each facility submitted information on the type and capacity of the treatment facility, plant performance, unit processes, personnel inventory and training, energy consumption, and other pertinent data. This data has been used for this study.

The facilities with trickling filters were contacted by telephone to get confirmation or updated information. The data obtained were analyzed and used to compile a scenario of trickling-filter treatment plants at Army facilities. Tables 1 through 7 summarize the data.

Table 1

Trickling Filter Flow Characteristics

Design Flow (mgd)	No.	%
0.01-0.1	5	7.3
0.1-0.5	21	30.8
0.5-1.0	10	14.7
1.0-2.5	19	27.9
2.5-5.0	10	14.7
5.0-10.0	3	4.4
Present Flow (mgd)		
0.001-0.01	2	2.9
0.01-0.1	12	17.6
0.1-0.5	24	35.3
0.5-1.0	9	13.2
1.0-2.5	19	27.9
2.5-5.0	1	1.5
5.0-10.0	1	1.5
Domestic Flow		
100%	16	23.5
85 + %	35	51.4
50-85%	10	14.7
10-50%	5	7.3
1-10%	2	2.9

Table 2

Trickling Filter Data,
Physical and Operational Characteristics

Filters per Plant	No.	%
1	24	39.3
2	29	47.5
3	3	4.9
4	5	8.2
	61	
Total Surface Area per Plant (sq ft)		
1-5,000	22	37.3
5,000-10,000	15	25.4
10,000-25,000	16	27.1
25,000-50,000	3	5.1
50,000 +	3	5.1
	59	
TF Dosing		
Continuous	29	61.7
Intermittent	18	38.3
	47	
TF Recirculation (mgd)		
0-3	24	92.3
3-10	1	3.8
10-20	1	3.8
	26	
TF Recirculation Ration		
0:1-1:1	24	57.1
1:1-5:1	14	33.3
5:1-10:1	4	9.5
	42	
TF Hydraulic Loading (mgd/acre)		
0.001-1.0	12	20.7
1.0-5.0	28	48.3
5.0-10.0	7	12.0
10.0+	11	19.0
	58	
TF Organic Loading (lb/day/acre-ft)	**No.**	**%**
0.1-50	11	21.2
50-500	17	32.7
500-1000	11	21.2
1000 +	13	25.0
	52	

Table 3

Trickling Filter Plant Data,
Plant Performance--BOD_5 Removal

	No.	%
BOD_5 Influent (mgd/L)		
1-50	16	30.8
50-100	9	17.3
100-150	13	25
150-200	11	21.2
200+	3	5.8
	52	
BOD_5 Effluent (mg/L)		
1-10	26	50
10-25	15	28.8
25-50	10	19.2
50 +	1	1.9
	52	
BOD_5 % Removal		
10-50	4	7.7
50-70	5	9.6
70-85	17	32.7
85 +	26	50
	52	
Filter Efficiency (% BOD_5 Removal		
10-50	7	12.7
50-70	18	32.7
70-85	19	34.5
85-100	11	20
	55	
TF Plants Not Meeting BOD_5 NPDES Compliance	12	25.5
	47	
Plants That Don't Require NPDES Permits	5	9.6
	52	

Table 4

Trickling Filter Plant Data,
Plant Performance--Suspended Solids Removal

SS Influent (mg/L)	No.	%
1-50	16	30.2
50-100	9	17
100-150	11	20.8
150-200	9	17
200 +	8	15.1
	53	
SS Effluent (mg/L)		
1-10	30	57.7
10-25	13	25
25-50	8	15.4
50-100	1	1.9
	52	
SS % Removal		
10-50	1	1.09
50-70	12	32.1
70-85	11	21.2
85+	28	53.8
	52	
TF Plants Not Meeting SS NPDES Compliance	10	21.3
	47	

Table 5

Industrial Wastewater Sources
Trickling Filter Plants in Army Facilities

Source	% Reporting Discharge to STP	% Reporting Pretreatment Before STP
Plating and Surface Preparation	12.3	6.2
Photographic Shop	40	9.2
Vehicle Aircraft/Washing	47.7	21.5
Heating (Boiler Plant)	55.4	7.7
Maintenance	44.6	9.2
Manufacturer of Propellants or Explosives	1.5	0
Other Metal Working	7.7	1.5
Fuel Storage	12.3	1.5
Cooling Systems/Towers	23.1	1.5
Laundry	44.6	6.2
Wet Scrubbers	10.8	3.1
Pesticides	10.8	0

Table 6

Trickling Filter Plant Data,
Operational Problems

Problem Identification	No. Trickling Filters	% Trickling Filters
Ponding	3	4.4
Flies	35	51.5
Odor	8	11.8

Table 7

Trickling Filter Plant Data
Operation and Maintenance Requirements

Plant Size (mgd)		Manhours/Week Operation	Manhours/Week Maintenance	Electricity (kW/month)	Percent of Personnel Certified (%) Supervision	Operation	Lab	Maint.
0.01-0.1	(Ave.)**	44.2	11.4	1,798	75	70	25	66
	(Range)	4-150	1-50	60-6,000				
0.1-0.5		54.3	23.6	5,550	66	72	22	43
		20-205	0-75	120-36,000				
0.5-1.0		157.1	28.2	19,353	58	82.5	66	100
		8-600	10-42	936-45,000				
1.0-2.5		98.4	47	85,362	70	67	50	50
		20-250	10-140	5,315-281,000				
2.5.5*		225	82	no data	100	100	100	0
		225	82					
5-10*		160	80	45,000	100	100	0	100
		160	80	45,000				

*Only one plant reported data for this size of facility.
**Top line for column entry is the average; bottom line is the range.

Scenario Description

The Army has 70 trickling-filter plants, which comprise 56 percent of its secondary treatment plants. Of these, 68 are currently in operation. About 84 percent of these trickling-filter plants were built before 1970, and the majority between 1940 and 1950. Although most of these plants have flows that are lower than their design values, their performance does not completely meet NPDES permits. Twelve out of 47 plants reported that their BOD_5 did not meet NPDES requirements (Table 3), and 10 reported that their suspended solids were not in compliance (Table 3). Therefore, there is a need to upgrade the performance of these plants.

Many facilities engineers and treatment plant supervisors have also identified other problems in their treatment facilities:

1. Insufficient manpower.

2. Inadequate training of personnel or difficulty in obtaining and retaining well-trained operators.

3. Stormwater infiltration.

4. Inadequate training to handle industrial wastes.

Many facilities have operators working on split shifts, servicing several sewage treatment plants and a water treatment plant in the same installation. The manhours/week data from Table 7 illustrates the problem of insufficient manpower for operating and maintaining the plants. Table 8 gives the manhour/week values converted to man-shifts. The data show that on the average, Army trickling-filter plants are understaffed, many of them critically. The problem becomes worse as plant size increases.

Table 8

Man-Shifts/Week Values

Plant Size (mgd)	Total Manhours/Week* Operations and Maintenance	Equivalent Man-Shift**
0.01 - 0.1	55.6	1.39
0.1 - 0.5	77.9	1.94
0.5 - 1.0	185.3	4.63
1.0 - 2.5	145.4	3.63
2.5 - 5.0	307.0	7.68
5.0 - 10.0	240.0	6.00

*Total manhours/week is the sum of the average manhours/week for operation and the average manhours/week for maintenance for each plant size category.

**Man-shift is 40 manhours/week.

Several problems identified by treatment plant personnel are equipment-related. Many plants are very old and are considered outdated. Difficulties in operation and poor performance of trickling filters are often associated with hydraulic and/or organic loadings. Although Table 2 indicates that the average operating condition of the existing Army trickling-filter plant is neither hydraulically nor organically overloaded, the data in Table 6 suggest otherwise. Odor is often associated with organic overloading. When organic overloading is excessive for long periods of time, heavy slime growth will accumulate on the surface of the support media and cause ponding. Ponding can sometimes result from the accumulation of chemical solids; however, it usually indicates organic overloading, because the heavy slime growth impedes the hydaulic flow through the filter.

Ironically, one difficulty in producing an effluent meeting the NPDES permits for BOD_5 percentage removal is that the influent BOD_5 is diluted by stormwater infiltration or large amounts of cooling water. The percentage of BOD_5 remaining in the effluent (usually 15 percent, i.e., 85 percent removal required) can be exceeded easily, even though the allowable effluent BOD_5 concentration can be met. For example, a plant with an influent of 120 mg/L* BOD_5 may be required to remove 85 percent of it to produce an effluent with concentration of 18 mg/L or better. When the influent is diluted to 80 mg/L BOD_5, the plant can meet the 18 mg/L BOD_5 requirement easily. However, it is very difficult for the plant to remove only 85 percent (i.e., 12 mg/L) of the BOD_5. Even a well-designed and well-operated plant, such as the one at Fort Lewis, would sometimes not meet the 85 percent BOD_5 removal requirement.

When a plant requires upgrading, many alternatives are possible. One option is replacing the trickling filters with other treatment technologies, such as activated sludge treatment, rotating biological contactor (RBC), oxidation ditch, or land treatment; however, abandoning use of the existing filter(s) is wasteful and usually very costly. Another alternative is to use a second treatment technology to polish the effluent and insure NPDES compliance. However, this method has two disadvantages: (1) the additional land required may not be available, (2) the operation of both trickling filters and another treatment technology in one plant adds to the complexity and effort required for successful treatment, and compounds the problem of obtaining adequately trained personnel.

A third alternative is to modify the existing trickling filter by replacing the rock-filtering media with plastic media. Still another option is to add one or more plastic media trickling filters to the existing rock filters for series or parallel operation. Important considerations in implementing these alternatives are: the improved performance provided by plastic media filters, the practicality and difficulty of trickling filter modification, cost-effectiveness, land requirement, the type of plastic media required, and operation and maintenance requirements of plastic-media trickling filters.

A plastic-media trickling filter plant provided for upgrade at Fort Lewis, WA, has two filter towers. Chapter 5 provides a detailed description of this plant. The Seneca Army Depot at Romulus, NY, formerly had two rock trickling-filter plants. To upgrade this system, one plant was completely

*Metric conversion factors are provided on p 133.

demolished, and a new RBC installed in its place. At the other, rock media were replaced with plastic media (see Chapter 5). The modification of the old trickling filter cost very little, and this plant is performing well; however, the new plant was quite costly and is having many operational problems. This case illustrates that sometimes replacing rock media with plastic media is all that is needed for upgrade; however, it should also be emphasized that this alternative may not be applicable to all Army plants (see Chapters 6 and 7).

Commonly Asked Questions About Plastic-Media Trickling Filters

Army engineers will have many questions about plastic-media trickling filters, including reliability, cost, and their advantages and disadvantages over rock media. The following text lists the most commonly asked questions and provides short answers to them. The answers contain references directing the reader to more detailed answers in other sections of this report.

1. *What are the rock trickling filter deficiencies?*

The conventional trickling filter uses rock, gravel, clinker, slag, granite, or similar material from 1 to 4 in. in diameter as the filtering media. The bed depth is usually 5 to 8 ft. The filter has limited ability to provide high surface area per unit volume because of its geometric configuration. Not only is there insufficient area for supporting the biological growth, but oxygenation is also poor due to the limited natural draft. In addition, uneven build-up and sloughing-off of sludge may plug the irregular and varied crevices between the filtering media. The filtering beds are usually shallow because deeper medium piles would intensify these problems.

Because of the limited depths in which they can be installed, conventional trickling filters are large in diameter. They are relatively limited in hydraulic and organic loading capability. Most conventional filters are operated in the 1 to 5 million gallons per acre per day (mgad) range; even the high-rate rock filters are limited to 10 to 50 mgad.

Since the conventional filtering meda are high in density, expensive underdrain structures are required to support them. The underdrain system drains the filtered effluent and permits air access.

2. *What is a plastic medium?*

There are two types of plastic filtering media: (1) a modular, self-supporting sheet-type synthetic medium usually fabricated from corrugated and rigid polyvinyl chloride (PVC) sheets, with modules normally about 2 ft wide by 2 ft high by 4 ft long, and (2) a ring structure made of PVC material measuring about 3 1/2 in. in diamter and 3 1/2 in. high. Both types have a very high void ratio of 95 percent or better and a high specific surface area, ranging from 27 to 104 sq ft/cu ft or 84 to 341 m^2/m^3. Both types of plastic media have a low density (about 1.4 to 1.6). Depending on the configuration of the module or the ring structure, their weights range from about 2.75 to 7.0 lb/cu ft or 44 to 112 kg/m^3. (By comparison, rock media weigh 90 lb/cu ft

or 1442 kg/m^3, with a 46 percent void space, and a specific surface area of 19 sq ft/cu ft, or 62 m^2/m^3.)

Chapter 4 provides more detailed answers.

3. *How are plastic media installed into the trickling filter?*

The 2-ft by 2-ft by 4-ft modules are stacked on top of the underdrain system in layers with a pattern recommended by the manufacturer. Corners can be cut by a chain saw to fit the filter geometry. No chemical bonding or thermo-welding is required. The ring-type plastic media are dumped at random into the filter, until the desired depth is attained. Thus, the large modules require more labor and time for installation. However, there will be some settlement of the ring media after filter start-up, so more rings will have to be filled in to achieve the designed depth.

Chapter 4 provides additional information.

4. *What are the advantages of using plastic media over the rock media?*

The high void ratio and high specific surface area of the plastic media allow a significant amount of biological growth, and the large voids provided between the media allow air to move freely through the filter. Hydraulic loading can be increased to the 300 to 400 mgad range, and organic loading can be increased to 100 to 300 lb of BOD_5/1000 cu ft of plastic media, depending on the nature of the waste.

The high void ratio and high specific surface area characteristics of the plastic media also make it possible to install them at much greater depths, which takes advantage of the fact that BOD_5 removal is a function of filter depth. The use of higher towers, rather than increased diameter, means that a lesser volume of media is used per unit of BOD_5 removed. Bed depths usually exceed 15 ft wide, with 20 to 25 ft commonly used for plastic media filters.

No expensive underdrain structure is required because plastic media are lightweight but self-supporting. The lightweight modular plastic media also allow the use of a low-strength retaining wall for the filter construction; random-fill media require somewhat stronger retaining walls, since there is some outward pressure from the combined weight of the biomass and the media.

It is possible to upgrade an existing rock filter with a minimal amount of modification by replacing the rocks with plastic media. Operation and maintenance requirements of the plastic media filters are essentially the same as for rock filters, so plant operators need no re-training.

5. *What are the disadvantages of using plastic media over rock media?*

Plastic media cost more and are not as resistant to chemicals. The warranty period for plastic media is usually limited to 1 year.

6. *When should plastic-media trickling filter technology be chosen?*

Consideration of plastic-media trickling filters should be given high priority when one or more of the following conditions applies:

a. Operational energy must be minimized.

b. Less demanding operator competence and training level are required.

c. An existing rock filter treatment plant is to be upgraded.

Of all the available secondary treatment technologies, trickling filters require the least amount of energy for operation. Also, trickling filters do not require the sophisticated control and monitoring of sludge age and food-to-microorganism ratio in the activated sludge process. For both upgrade and new construction, the use of plastic media is usually more economical and does not require new training for treatment plant operators.

When one or more of the following conditions applies, the use of plastic-media trickling filters should be given very low priority:

a. The presence in the wastewater of chemical(s) that attack PVC or similar plastic materials is suspected.

b. High operational flexibility comparable to that obtained with the activated sludge process is required.

Chapters 6 and 7 provide more detail.

7. *What are the design criteria of different filters and their expected performance?*

The requirements of primary and secondary clarifiers are the same for both rock and plastic-media filters. Sludge generation and sludge characteristics are also the same. Operation and maintenance requirements are almost the same, except that the effluent recirculation ratio is usually lower for plastic-media filters with deeper beds. Table 9 provides various trickling filter design criteria.

8. *What is the plastic media reliability?*

Many plastic-media trickling-filter plants have operated since the early 1960s without media failure. Even if some breakage of the plastic media occurred in the filtering bed, plant operation or the performance would not be affected, in contrast to the RBC treatment system, in which broken plastic media could fall off and jam the mechanical and air-drive systems of the unit or cause shaft failure.

Table 9

Trickling Filter Classification

Design Characteristics	Standard (Low) Rate	Intermediate Rate	High Rate (Rock Media)	High-Super Rate (Plastic Media)	Super Rate (for Roughing)
Hydraulic Loading					
gal/sq ft/day	25-100	100-230	230-1000	350-2100*	1400-4200
m^3/m^2/day	1.0-4.1	4.1-9.4	9.4-40.8	14.3-85.7	57.1-171.4
mgad	1.1-4.4	4.4-10.0	10.0-43.5	15.2-91.4	61.0-182.9
Organic Loading					
lb BOD_5/1000 cu ft/day	5-25	20-30	25-300	Up to 300	100-plus
kg BOD_5/m^3/day	0.08-0.40	0.32-0.48	0.40-4.80	Up to 4.80	1.60-plus
lb BOD_5/acre-ft/day	218-1089	875-1307	1089-13068	Up to 13068	4356-plus
Recirculation (Ratio)	Minimum (0)	Usually (0.5-3)	Always (0.5-3)	Usually	Not Required
Filter Flies	Many	Varies	Few	Few	Few
Sloughing	Intermittent	Varies	Continuous	Continuous	Continuous
Depth of Bed, ft	5-8	5-8	4-8	Up to 40	3-20
BOD_5 Removal, %	80-85	50-70	65-80	65-85	40-65
Effluent Nitrification	Good	Some	Nitrites	Limited	No

*Not including recirculation.

Note: 1 gal/sq ft/day = 0.0408 m^3/m^2/day = 0.04354 mgad = 407.52 m^3/ha/day; 1 lb BOD_5/1000 ft^3/day = 0.016 kg BOD_5/m^3/day = 43.56 lb BOD_5/acre-ft/day = 0.027 lb BOD_5/yd^3/day

9. *Have any plastic-media trickling filtering plants been installed at U.S. Army installations?*

Fort Lewis, WA, has a trickling-filter plant with two plastic media towers, and one of the two plants at Seneca Army Depot, NY, is a modified trickling-filter plant with plastic media. Fort Stewart is partner in a construction project building a regional treatment plant which is state of the art. Chapter 5 provides additional details.

10. *Who are the major plastic media manufacturers?*

B. F. Goodrich
Engineering Products Group
500 South Main Street
Akron, OH 44318
216-374-4136

Norton Industrial Ceramics Division
Worcester, MA 01606
617-853-1000

The Munters Corporation
P.O. Box 6428
Fort Meyers, FL 33901
813-936-1555

Koch Engineering Company, Inc.
4111 E. 37th Street
North Wichita, KS 67208
316-832-5110

American Surfpac Corporation
P.O. Box 424
West Chester, PA 19380
215-692-9900

3 IDENTIFICATION OF TREATMENT TECHNOLOGY SELECTION CRITERIA

Table 10 summarizes information for choosing a wastewater treatment technology that is most applicable to a specific site.

In choosing a wastewater treatment technology, initial costs and particularly Operation and Maintenance (O&M) costs are the primary considerations of Corps of Engineers (CE) District Offices and Facilities Engineers. Operator training time, manhour requirements, and the site-specificity of a treatment system application are also important considerations. Most District offices use EM 1110-2-501, Part 1, Design of Wastewater Treatment Facilities Major Systems, as a guide for their system design, and some also use EPA design manuals, state manuals, and other technical publications.

Table 10

Information and Mechanism for Choosing Treatment Technology

	Mechanism To Choose Treatment Technology	Information Required by CE Personnel	Information Available to CE Personnel
Alaska	Initial cost, O&M cost analysis, reliability evaluation	State standards; EPA requirements	Army TM 5-814-3, Domestic Wastewater Treatment; EM 1110-2-501, Part 1, Design Wastewater Treatment Facilities; Major Systems; Various technical papers on Alaska experience.
Baltimore	EM 1110-2-501, Part 3; state design standards; NPDES permit	NPDES permit	See above.
Fort Worth	Life-cycle cost evaluation	---	EM 1110-2-501, Part 1; various technical publications.
Galveston	---	---	State manuals; Texas Wastewater Utilities Assoc.
Hungtington	Experience	State requirements	EM 1110-2-501, Part 1.
Little Rock	State standards; minimal O&M and personnel requirements	State standards	State regulations; 10 state standards; EPA regulations, and manuals.
Mobile	Least O&M costs	State effluent regulations	EM 1110-2-501, Part 1.
Nashville	EPA and state-approved technology	State and EPA requirements	See above.
Omaha	Initial cost, O&M costs, state standards and requirements	State standards	Technical publications, text books; manufacturers' publications; EM 1110-2-501, Part 1.

Table 10 (Cont'd)

	Mechanism To Choose Treatment Technology	Information Required by CE Personnel	Information Available to CE Personnel
Pittsburgh	State and Federal requirements	10 state standards; EPA design manuals; state permits	All regulations; ETLs, ETNs, EPA manuals and design books; state manuals and permits.
Portland	---	State regulations	EM 1110-2-501, Part 1.
Rock Island	Initial cost; O&M costs; available trained personnel; state and local regulations	State regulations	ERs, ETLs, EMs; standard textbooks; state and local regulations.
Seattle	Cost	ETLs	State regulation.
St. Paul	Effluent limitations; land available; water table elev.; state-of-the-art technology	---	EM 1110-2-501, Part 1.
Tulsa	Evaluation performance of existing installations	State and Federal data	ETLs and Engineering manuals.
Waltham	Cost	ETLs, ETNs, Engineering Manuals	ETLs, ETNs, Engineering Manuals.
Wilmington	Cost; soil evaluation; state and county regulations; O&M requirements	State and local requirements	EMI 1110-1-501, Part 1.

4 PLASTIC-MEDIA TRICKLING FILTER CHARACTERISTICS, DESIGN, O&M, AND NEW DEVELOPMENTS

A literature survey was conducted to determine the design, operation, and maintenance characteristics of trickling filters with plastic media. In addition, a phone survey was made of several wastewater treatment facilities that are using plastic-media trickling filters, including municipal, industrial, as well as military institutions. The purpose of the phone survey was to determine the plastic media's reliability and the treatment performance experienced by these plants. The facilities surveyed were:

Ambler Sewage Treatment Plant
Ambler, PA 19002
215-728-9457

Waste Treatment Plant
140 Church St.
Phoenixville, PA 19460

Morton Frozen Foods
Crozet, VA
804-823-5111

U.S. Gypsum
Oakfield, NY
716-948-5221

U.S.M.C. Station
Paris Island, SC
803-525-2111

Gretna WWTP
Gretna, LA
504-366-6121

Wastewater Treatment Plant
New Windsor, NY
914-565-8802

Lebanon Sewage Treatment Plant
Lebanon, PA 17042
717-272-2841

McClellan Air Force Base
Sacramento, CA
916-643-4875

Alcoa
Lafayette, IN
317-447-4141

A. E. Staley Co.
Lafayette, IN
317-474-5474

Newcomerstown WWTP
Newcomerstown, OH
614-498-7246

Waste Treatment Plant
New Providence, NJ
201-665-1077

Types of Plastic Filtering Media

Several brands of plastic trickling-filter media of two basic designs are on the market. The first type--a modular, self-supporting medium which comes prefabricated in block form or is constructed onsite--constitutes about 95 percent of the applications. Most manufacturers of modular media produce a variety that are modified for shallow filters. The second type is a ring-structured random fill medium.

The media are made of several types of plastic material, such as polyurethane, polypropylene, and PVC. PVC is strong and is the most resistant to chemicals. Some of the manufacturers offer a choice of materials, while

others do not. Manufacturers produce media in different strengths, configurations and adaptations for particular functions. Their literature should be consulted for additional information.

Advantages and Disadvantages of Using Plastic Media

Plastic media have several advantages over conventional rock media, which lead to greater efficiency of BOD_5 removal. The plastic media provide greater surface area to volume ratio, permit better air flow through the filter bed due to increased porosity (greater than 90 percent void space), decrease the possibility of plugging, and provide a better means of liquid distribution than rock media.

The relatively high surface area to volume ratio of plastic media contributes substantially to the filter efficiency. Large surface areas permit an extensive growth of organisms to exist within the trickling filters in relatively thin layers. According to Egan, et al.,

> By providing increased surface area the plastic media tend to maintain the necessary mass of organisms required to purify the waste although in relatively thin sheets of slime.
>
> The available surface area of a filter media has a definite effect on the removal capabilities of a trickling filter, providing the geometric design of the medium doesn't allow any free fall of the wastewater. The removal rates and efficiencies showed an appreciable increase as the surface area was increased, but there appeared to be an upper limit of specific surface area (approximately 27 ft^2/ft^3) after which the removal rate and efficiency was not as great as before.[1]

Table 11 demonstrates some of the advantages of plastic media. The available surface area of a conventional stone trickling filter is about 19 sq ft/cu ft, which is well below the optimum. The available surface areas of plastic module media are 25 to 30sq ft/cu ft--very close to the optimum of 27 sq ft/cu ft. The void space in the stone filter is about 46 percent, as compared to 94 to 97 percent in the modular plastic media. The larger percentage of void space assures that the filter will not become plugged. The most obvious advantage of the plastic media is the great weight reduction; thus, less expensive, lightweight towers can be used with the plastic media.

The plastic trickling-filter medium is more expensive than conventional stone or slag. But this added expense can be offset by a reduction in the cost of its housing and a decrease in the land area required, since the units can be built higher.

[1] J. T. Egan and M. Sandlin, "The Evaluation of Plastic Trickling Filter Media," Purdue Proceedings, Vol 15 (Purdue University, 1960), pp 107-119.

Table 11

Comparative Physical Properties of Biological Filter Media

(From Process Design Manual for Upgrading Existing Water Treatment Plants, Roy F. Weston, Inc., U.S. Environmental Protection Agency [USEPA], October 1971.)

Unit	Weight (lb/cu ft) (kg/m^3)	Specific Surface Area (sq ft/cu ft) (m^2/m^3)	Void Space (Percent)	Channel Spacing (in.) (cm)
Stone	90 (1442)	19 (62)	46	0.1-1.0 (0.25-2.54)
Random Packed Plastic	--- ---	25-80 (82-262)	80-90	0.1-0.5 (0.25-1.27)
Wood	10.3 (1.65)	14 (46)	---	--- ---
Plastic Modules (e.g., Surfpac Tower)	2-6 (32-96)	25-30 (82-98)	94-97	1.0 (2.54)

Conventional rock trickling filters have certain disadvantages, including large land area because of their shallow filters, the massive structure needed to support the weight of the packing, and the tendency of solids to occlude the voids in the packing.

It is advantageous to have a taller filter, because at a given flow rate, both the percentage of and the total BOD_5 removed tend to be greater in a tall filter than in a shallow one. Plastic media filters can be built quite tall (20 ft or more), whereas rock filters are usually built to depths of 8 ft or less.

Compared to rock media, the greater treatment obtainable from a given packed volume of synthetic medium results in a proportional reduction in the size of a filter needed to treat a given waste.

The use of lightweight construction materials is feasible with the lightweight plastic media. Thus, expensive underfloor drains are unnecessary, and only simple sumps capable of withstanding the weight of a few inches of water are necessary.

The nature of the solids voided from the plastic media system permits the use of smaller sedimentation tanks, since the sludge solids are more readily separable and more easily dewatered than conventional installations.

The more compact and less complicated installations readily lend themselves to automation and reduction in the labor required.

A pilot plant study by the Eastman Kodak Company showed that a plastic-packed trickling filter would require one-fifth of the land area of a stone-packed unit. The plastic filter was 21.5 ft deep and the stone filter 8 ft deep.

Trickling filters are known for process stability, operating economy, and low energy consumption as opposed to activated sludge processes which depend greatly on the operator skill to achieve high removal efficiency and stability of treatment.

Trickling filters with depths under 10 ft require a much larger amount of media to produce an effluent equivalent to that produced by a deep filter. A 20-ft filter would require half as much volume of media to provide the same BOD_5 removal as a 10-ft-deep filter. Thus, the depth of a filter has a significant effect on the volume required. Although plastic media filters are much deeper than conventional filters, very little recirculation of filter effluent is required. Consequently, energy consumption is not high. Random fill media such as Actifil or Flexirings have the added advantage that no special placement pattern or cutting is necessary. The media are randomly dumped, so they can be easily installed in any size or shape of tank.

In summary, the main advantages of plastic media trickling filters are:

1. Low energy consumption

2. Reliable performance

3. Resistance to hydraulic and organic shockloads

4. Unsophisticated operational procedures

5. Effective land use

6. Reduction in sludge bulking problems and production of a more easily handled waste sludge. The filter fly problem is minimized due to the high hydraulic loading used in filter operations.

Using plastic media also has certain disadvantages. Plastic media are much more expensive than the conventional rock media, so a cost-effectiveness analysis should be done before plastic media are adopted for use. Certain disadvantages associated with rock filters also occur in plastic filters. In cold climates, ice tends to build up on the filter media and on the distributor arms, which can actually freeze up and stop the filter operation. Although filter flies and odor are not as great a problem in plastic media, they do occur. Domes can be added to combat these problems.

Periodic maintenance will be needed to unclog nozzles in the distributor arm that get plugged with rags and other debris. Planks should be laid on top of the plastic media before walking on them. Sometimes the plastic media are damaged when operators step directly on the media while providing service to the filter, such as unplugging the nozzles or changing the bearing of the central column.

Filter Performance and Improvement Over Rock Filters

Trickling filter performance is affected by several factors, including media size, type of media, media depth, ventilation, hydraulic loading, organic loading, and temperature variation.

Trickling filters operate more efficiently in a warm climate. Cold weather has several adverse effects, such as icing on the filter, which can temporarily halt its operation. A few measures to reduce cold weather effects include the construction of wind breaks, adding more freeboard to the filter walls, reducing or eliminating recirculation, covering the filter with a dome, and warming the influent wastewater with pumping motor heat.

Benzie, et al.[2] found significant differences in trickling filter efficiencies between winter and summer months. This study was done in Michigan, where the mean summer air temperature was 67 to 73°F and the mean winter temperature range was 23 to 31°F--a 42°F seasonal difference.

Lower air temperature has a more significant effect on reducing filter efficiencies in plants that recirculate than in those that do not. In plants with recirculation, the winter efficiency was 21 percent less than the summer efficiency. In plants without recirculation, the winter efficiency was 12 percent less than the summer efficiency. This is because recirculation tends to cool the influent, causing reduced removal. Since plastic-media trickling filters use a much lower rate of recirculation than the conventional rock filters, a better BOD_5 removal efficiency can be expected in the winter.

The efficiency of a trickling filter will start to decrease after the optimum organic and hydraulic loads are surpassed. The optimum loadings depend on the type of media as well as the tower depth. BOD_5 removal is a function of the BOD_5 concentration of the wastewater and the adsorptive capacity of the biological growth.

Table 12 shows the results of a study by Wing and Steinfeldt[3] in which the hydraulic loading effects of rock- and plastic-packed trickling filters were compared for treating industrial waste.

The same patterns shown in Table 12 for industrial waste can be correlated to domestic waste.

---

[2]W. J. Benzie, H. O. Larkin, and A. F. Moore, "Effects of Climatic and Loading Factors on Trickling Filter Performance," JWPCF, Vol 35 (1963), pp 445-455.

[3]B. A. Wing and W. M. Steinfeldt, "A Comparison of Stone-Packed and Plastic-Packed Trickling Filters," JWPCF, Vol 42 (1970), pp 255-264.

Table 12

Hydraulic Loading Comparison for Rock- and Plastic-Packed Trickling Filters

Stone-Packed	Hydraulic Loading 3.6 mgad	13.8 mgad
Basic Efficiency	36%	24%
+		
Forced Draft	44%	38%
+		
Recycle (7.5:1)	80%	51%
+		
Nutrients	80%	51%

Plastic-Packed Trickling Filter	Hydraulic loading 16 mgad	60 mgad
Basic Efficiency	64%	43%
+		
Forced Draft	66%	43%
+		
Recycle (4:1)	76%	43%
+		
Nutrients	76%	43%
+		
6 Months Time	85%	

As shown in Table 12, a greatly increased hydraulic loading lowers the efficiency of both the rock- and plastic-packed filters. The comparison also shows that the plastic media can treat a much greater hydraulic load and obtain equivalent or better efficiency. The results indicate that a much smaller volume of plastic media would be required to treat the same amount of waste.

Two efficiency curves from plastic media manufacturers (see Figures 1 and 2) compare the performance of Biodek and rock and Flexipac and rock with percent BOD_5 removal versus pounds of BOD_5 applied per 1000 cu ft per day. The curves show a great difference between the rock and plastic media. The plastic media obtain 65 percent removal at applied BOD_5 rates of 400 lb per 1000 cu ft per day, whereas the rock media fall below 50 percent removal at about 165 lb.

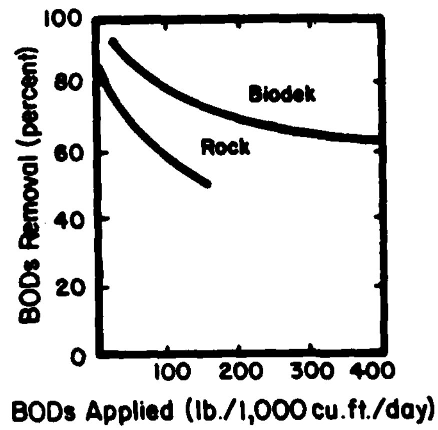

Figure 1. Biodek vs. rock efficiency curve.

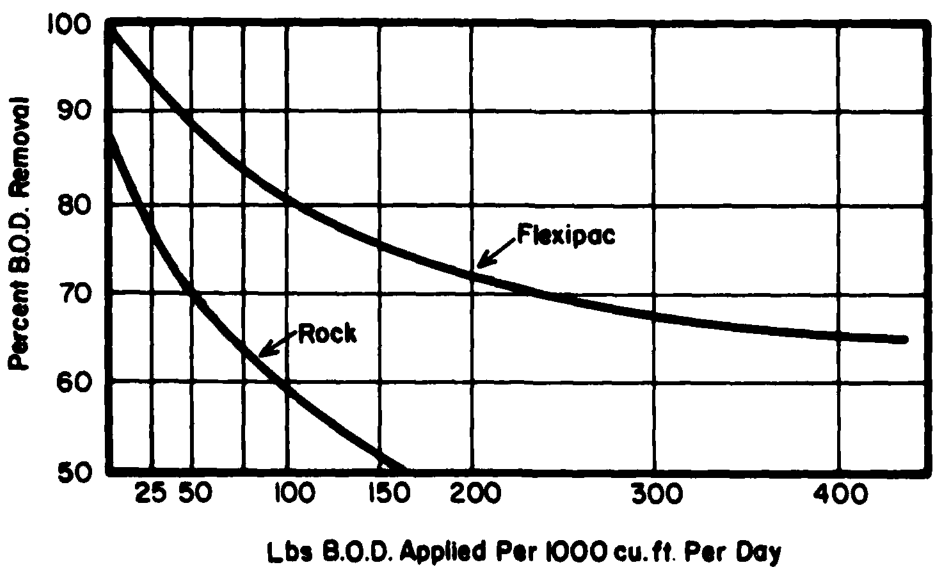

Figure 2. Flexipac vs. rock efficiency curve.

The organic and hydraulic loadings significantly affect a trickling filter's removal capabilities. Figure 3 shows the relationship of percent Chemical Oxygen Demand (COD) remaining with depth (constant flow rate and varying organic concentrations). The lowest feed concentration of 100 mg/L had the highest removal of about 87 percent. The next higher feed concentration of 200 mg/L showed a removal of about 82 percent, and the highest feed concentration of 300 mg/L showed a drastic decrease--about a 55 percent removal. This shows that the higher the organic load to the filter, the less efficient the trickling filter becomes.

Figure 4 shows the relationship of percent COD remaining with depth (constant substrate concentration and varying flow rates). The higher the flow rate, the lower the percent COD removal at any given depth. At the lowest flow rate of 100 gpd/sq ft, the highest removal was found to be about 87 percent. At the next higher flow rate of 200 gpd/sq ft, the COD removal was about 79 percent. At the highest concentration, the COD removal was about 56 percent.

Generally, the optimum removal for a specific flow and waste concentration must be determined with pilot plant studies. The optimum removal will depend on the media type, depth, and retention time.

Generally, weaker wastes have higher percentage removals than stronger wastes. The same is true for hydraulic loading (i.e., lower hydraulic loadings will have higher percentage removals).

Design Equations

There are numerous equations for the design of trickling filters in the literature. Many were developed assuming certain BOD_5 removal kinetics, while others were developed empirically using statistically analyzed performance data. Although the following trickling filter formulas represent attempts to include many of the variables affecting trickling-filter operation, use of any one of these formulas is an approximation and does not universally predict the actual performance of trickling filters. Based on the design variables and criteria used, these equations or models are divided into five groups for discussion.

Group 1. BOD_5 Removal Efficiency as a Function of BOD_5 Loading per Unit Volume of Media and Recirculation Factor

The equation was developed by the National Research Council (NRC) using operating data from plants serving military installations during World War II.[4]

First or single stage:

$$E = \frac{100}{1 + 0.0085\left(\frac{W_1}{VF}\right)^{1/2}} \qquad \text{[Eq 1a]}$$

[4] National Research Council, "A Mathematical Model for Trickling Filter Design," Sew. Works Jour., Vol 18, No. 791 (1946).

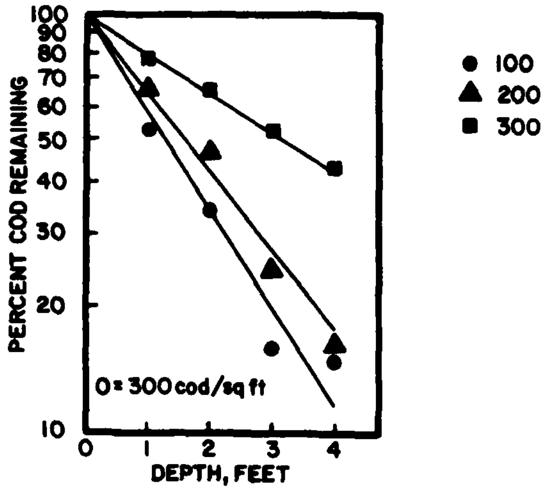

Figure 3. Relationship of percent COD remaining with depth (constant flow rate and varying organic concentrations).

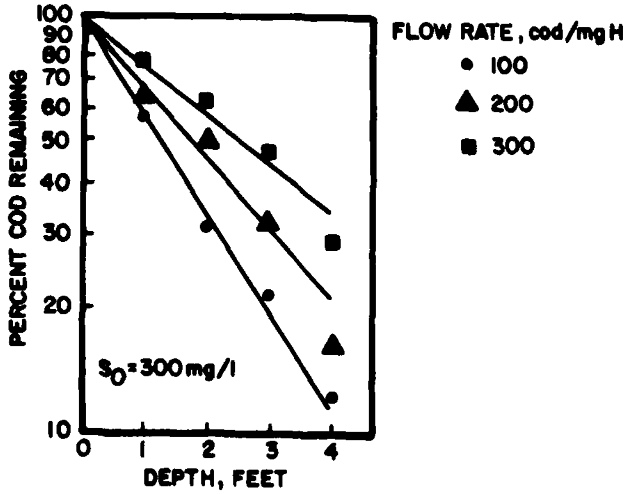

Figure 4. Relationship of percent COD remaining with depth (constant substrate concentration and varying flow rates).

Second stage:

$$E_2 = \frac{100}{1 + \frac{0.0085}{1 - E_1}\left(\frac{W_2}{VF}\right)^{1/2}} \qquad \text{[Eq 1b]}$$

where:

E_1 = percent BOD_5 removal efficiency through the first-stage filter and settling tank

W_1 = BOD_5 loading (lb/day) to the first or single-stage filter, not including recycle

V = volume of the particular filter stage in acre-ft (surface area times depth of media)

F = number of passes of the organic material, equal to $(1 + R/I)/[1 + (1 - P)\ R/I]^2$

where R/I equals the recirculation ratio (recirculated flow/plant influent flow), and P is a weighting factor which, for military trickling-filter plants, was found to be approximately 0.9

E_2 = percent BOD_5 removal efficiency through the second-stage filter and settling tank

W_2 = BOD_5 loading (lb/day) to the second-stage filter, not including recycle.

Some of the limitations of the NRC formulas are:

1. Military wastewater is characteristically more concentrated than average domestic wastewaters.

2. The effect of temperature on trickling-filter performance is not considered (most of the plants studied were in the middle latitudes of the United States).

3. NRC formulas indicate that organic loading has a greater influence on filter efficiency than hydraulic loading. This is probably because of the concentrated nature of the wastewaters.

4. Applicability is limited to concentrated domestic wastewaters because no factor is included to account for differing treatability rates.

5. The formula for second-stage filters is based on the existence of intermediate settling tanks following the first-stage filters.

When the applied BOD_5 load is known and both the percent BOD_5 removal efficiency and recirculation factor are specified, the volume of media required can be calculated; from this, the size of the filter is determined.

Group 2. Empirically Developed Equations

Several equations are included in this group:

$$L = \frac{K(Q_i L_o + Q_r L_e)^{1.19}}{(Q_i + Q_r)^{0.78} (1+D)^{0.67} a^{0.25}} \qquad \text{[Eq 2]}$$

$$\text{with } K = \frac{0.464\left(\frac{4.3560}{\pi}\right)^{0.15}}{Q_i^{0.28} T^{0.15}}$$

where L_o, L_e = influent and effluent BOD_5 at 20°C concentrations, respectively, mg/L

Q_i, Q_r = influent and recirculation flow rates respectively, mgd

D = filter depth, ft

a = filter radius, ft

T = wastewater temperature, °C.[5]

K = a constant dependent on wastewater temperature (T) and influent flow (Q_i).

The effects of recirculation hydraulic loading, filter depth, and wastewater temperature are important in predicting trickling-filter performance:

$$E = (1+Q_r/Q_i)/(1.5+Q_r/Q_i) \qquad \text{[Eq 3]}$$

This equation applies only if the following conditions are met:

Maximum daily load = 1.77 kg BOD_5/m^3 or 110 lb BOD_5/1000 cu ft

Filter depth is within a range of 1.52 to 2.13 m (5 to 7 ft)

Filter influent BOD_5 concentration not to exceed 3 times the effluent BOD_5 concentration.

Hydraulic loading is within a range of 9.88 to 29.65 m^3/m^2 day or 10 to 30 mgad.[6]

[5] H. B. Gotaas and W. S. Galler, "Design Optimization for Biological Filter Models," Journal of the Environmental Engineering Division, ASCE, Vol 99 (1973), pp 831-849.

[6] V. Hanumanula, "Performance of Deep Trickling Filters by Five Methods," JWPCF, Vol 42 (1970), pp 1446-1457.

The formulation is based on data from rock-filter data from cold regions.

Group 3. BOD_5 Removal Rate as a Function of Filter Depth or Hydraulic Detention Time

This group includes equations that can be expressed in the following general form:[7]

$$L_e/L_o = \exp\left[-k(D/Q_i^n)\right]$$

where the hydraulic detention in the filter is a function of depth and influent flow rate:

In 1948, Velz proposed the first major formulation delineating a fundamental law as contrasted to previous empirical attempts based on data analyses. This relationship is applicable to all biological beds, low-rate as well as high-rate trickling filters. The Velz formula relates the BOD_5 remaining at depth D as follows:

$$L_D = 10^{-KD} \qquad \text{[Eq 4]}$$

where:

L = total removable fraction of BOD_5, mg/L,

L_D = removable BOD_5 at depth D, mg/L,

D = filter depth, ft

K = first-order rate constant, day^{-1}.

Removable BOD_5 in the Velz formula is defined as the maximum fraction of applied BOD_5 removed at a specific hydraulic loading range.

Temperature was assumed to affect the rate of removal in accordance with:

$$K_T = K_{20} \times 1.047^{(T-20)} \qquad \text{[Eq 4a]}$$

where:

K_T = rate constant at any temperature, T, °C

K_{20} = rate constant at 20°C.

For high-rate filters, the value of rate constant K at 29°C was determined to be 0.1505 day^{-1}.

[7] C. J. Vetz, "A Basic Law for the Performance of Biological Filters," Sew. Works Jour., Vol 20, No. 607 (1948); K. L. Shulze, "Load and Efficiency of Trickling Filters," Jour. WPCF. 32, (1960), pp 245-261; W. E. Howland, "Flow Over Porous Media as in a Trickling Filter," 12th Ind. Waste Conf., Purdue, 42 (1958), pp 435-465.

Low-rate trickling filters yielded an approximate K-value for 29°C of 0.175 day^{-1}.

The major deficiencies in this first rational approach to establish a trickling-filter performance guide are the assumptions that hydraulic loading does not affect efficiency, and that the rate constant, K, was a first-order reaction, regardless of the participating organisms and the amount of recirculation.

In 1960, Schulze[8] postulated that the time of liquid contact with the biological mass is directly proportional to the filter depth and inversely proportional to the hydraulic loading rate. This is expressed as follows:

$$t = \frac{CD}{Q^n} \qquad \text{[Eq 4b]}$$

where:

t = liquid contact time, min

C = constant

D = filter depth, ft

Q = hydraulic loading rate, gpm/sq ft

n = constant, characteristic of the filter media.

Combining the time of contact with the first-order equation for BOD_5 removal, in an adaptation of the Velz theory, Schulze derived the following formula:

$$\frac{L_e}{L_i} = e^{-kD/Q^n} \qquad \text{[Eq 4c]}$$

where:

L_e = BOD_5 of unsettled filter effluent, mg/L

L_i = BOD_5 of filter influent, mg/L

k = an experimentally determined rate constant between 0.51 and 0.76 day^{-1}

n = constant characteristic of the filter media

D = filter depth, ft

Q = hydraulic loading rate, gpm/sq ft.

[8] K. L. Schulze, "Load and Efficiency of Trickling Filters," Jour. WPCF. 32 (1960), pp 245-261.

This equation is similar to that proposed by Velz. Where it differs is that Velz's constant, K, was not formulated to consider hydraulic load, while Schulze's k does:

$$k(\text{Schulze}) = [k(\text{Velz})](Q^n),$$

where Velz's K is now to the base e.

The dimensionless constant characteristic of stone-filter media, n, was taken as 0.67. A temperature correction could be applied for k:

$$k_T = k_{20} \times 1.035^{(T-20)} \qquad \text{[Eq 4d]}$$

This temperature effect concept was introduced by Howland.[9] In this example, 1.035 is Θ, the temperature coefficient.

Group 4. Models Incorporating the Effect of Filtering Media on BOD_5 Removal

Several equations were developed to modify Eqs 1 through 3. Recognition of the importance of the effect of filtering media and their packing in the filter bed is incorporated in these later developed equations. Effects include determination of hydraulic characteristics, detention time, and amount of biofilm development on the media before limiting of the oxygen supply.

$$\frac{L_e}{L_o} = \exp\left(\frac{-kD^m}{q^n}\right) \qquad \text{[Eq 5]}^{10}$$

where:

L_e = effluent BOD_5, mg/L

L_o = influent BOD_5, mg/L

K = reaction-rate constant related to specific surface

D = depth, ft

q = hydraulic loading, mgad

n = constant related to specific surface and configuration of packing of media

m = constant, usually assumed as 1.0; indicative of biological slime distribution with filter depth.

[9] W. E. Howland, pp 435-465.
[10] W. W. Eckenfelder, Jr., "Trickling Filter Design and Perforamnce," Jour. San. Engr. Div. ASCE, Vol 87, No. SA4 (July 1961), pp 33-45.

When recirculation applies,

$$\frac{L_e}{L_a} = \exp\left(\frac{-kD^m}{q^n}\right) \qquad \text{[Eq 6]}$$

where: L_a = BOD_5 in raw wastewater following dilution with recycle flows, units in mg/L

$$L_a = \frac{L_o + RL_e}{(1 + R)}$$

where:

R = recirculation ratio 9/9

L_e = BOD_5 remaining in the filter effluent

For temperature correction, Eckenfelder[11] suggests θ = 1.02 to 1.072, in using the equation $k_T = k_{20}\ \theta^{T-20}$. The values of m and n are constant for a given filter, reflecting the type of medium used (e.g., rock, slag, plastic ring, etc.) and how it is packed in the filter. When the m value is assigned to 1.0, the n values for various types of media can be found from Table 13.

$$D = -\frac{(q^n)\ \ln\left[\frac{L_e + L_e\ (R)}{L_o + L_e\ (R)}\right]}{K\ (A_p)} \qquad \text{[Eq 7][12]}$$

where:

D = depth of filter, ft

q = hydraulic loading, gpm/sq ft

n = media factor

L_e = desired effluent BOD_5, mg/L

L_o = influent BOD_5

K = reaction rate constant

A_p = specific surface area of the media sq ft/cu ft

The exponent n is usually assigned a value of 0.5 for plastic media or determined by laboratory analysis.

---

[11] W. W. Eckenfelder, Jr., Industrial Water Pollution Control (McGraw-Hill, 1966).

[12] Design of Wastewater Treatment Facilities Major Systems, EM 1110-2-501, part 1 of 3 (Office of the Chief of Engineers, September 1978).

Table 13

Summary of BOD_5 Removal Characteristics of Various Media Treating Settled Wastewater

(From Balakaishnan, S., et al., "Organics Removal by a Selected Trickling Filter Media," Water and Wastewater Engineering, Vol 6, No. 1 [1969].)

Description	Specific Surface (sq ft/cu ft)	Temperature Range (°C)	Influent BOD_5 Range (mg/L)	Depth (ft)	Hydraulic Loading Range (mg/acre/day)	n^o	K^o at 20°C
1 1/2-in. flexirings	40.0	2-26	65-90	8	12.5-26.9	0.39	0.46
1-in. clinker	61.5	7-17	220-320	6	0.96-1.2	2.56	0.865
2 1/2-in. clinker	37.4	7-17	220-320	6	0.96-1.2	0.84	0.685
1-in. slag	60.0	7-17	220-320	6	0.96-1.2	0.30	0.865
2 1/2 in. slag	33.0	7-17	220-320	6	0.96-1.2	0.75	0.640
1-in. rock	43.3	7-17	220-320	6	0.96-1.2	2.36	0.74
2 1/2-in. rock	27.6	7-17	220-320	6	0.96-1.2	3.80	0.645
1-in. rounded gravel	44.5	7-17	200-320	6	0.96-1.2	3.00	0.625
2 1/2-in. rounded gravel	19.7	7-17	220-320	6	0.96-1.2	5.40	0.57
Surfpac	28.0	24	200	21.6	31-250	0.50	0.395
Surfpac	28.0	24	200	12	62-250	0.45	0.33
2 1/2- and 4-in. rock filter	15.0	24	200	12	31-94	0.49	0.275
1 1/2- and 2 1/2-in. slag	42.0	7-17	112-196	6	5-12.5	1.0	0.87
1- to 3-in. granite	29.0	16-18	186-226	6	2-16	0.4	0.312
3/4-in. Raschig rings	75.8	16-18	186-226	6	2-16	0.7	0.55
1-in. Raschig rings	52.2	16-18	186-226	6	2-16	0.63	0.42
1 1/2-in. Raschig rings	35.0	16-18	186-226	6	2-16	0.306	0.28
2 1/4-in. Raschig rings	22.7	16-18	186-226	6	2-16	0.276	0.25
Straight block	28.2	16-18	186-226	6	2-16	0.345	0.2

Notes: n and K are constants; m is equal to 1.

$$\frac{L_e}{L_o} = \exp\left[-Kp(V/695Q_i)^{0.5}\right] \qquad \text{[Eq 8]}^{13}$$

where:

V = attached growth media volume, cu ft

K_p = performance measurement parameter equal to 0.265 + ln (q_w)/20 and q_w equal to hydraulic rate, gpm/sq ft

L_e = effluent BOD_5

L_o = influent BOD_5

Q_i = influent flow, mgd

[13] H. H. Bonjes, et al., Capital and O&M Cost Estimates for Biological Wastewater Treatment Processes (USEPA, 1979).

The values of the K_p and the corresponding q_w values are given as:

Filter media	q_w	k_p
Rock	0.1 gpm/sq ft	0.15
Rock	0.2	0.18
Rock	0.3	0.20
Rock	0.4	0.22
Plastic	0.75	0.23

Group 5. Diffusion Models

These equations or models were developed assuming that the BOD_5 removal rate is controlled by the rate of flux of either organic matter or oxygen into the slime layer.

$$\frac{L_e}{L_a} = \mathrm{EXP}\ [-S(fh\ k_o)\ \frac{WD}{Q_i}] \qquad \text{[Eq 9]}^{14}$$

where:

w = width of slime layer section under consideration

L_a = initial BOD_5

f, h, and k_o are from the rate of flux expression for organic matter into the slime layer, R_s, or

$$R_s = -fh\ k_o \frac{\bar{S}^2}{k_s + \bar{S}} \qquad \text{[Eq 10]}$$

where:

f = proportionality factor

h = thickness of slime layer

k_o = maximum reaction rate, day^{-1}

$\bar{S}$ = average BOD_5 concentration in the bulk liquid in volume element

k_s = half-velocity constant.

[14] B. Atkinson, et al., "The Overall Rate of Substrate Uptake by Microbial Films, Parts 2 and 22," Trans. Inst. Chem. Eng. (1974).

For practical application, the equation can be transformed by grouping (fhk_o) into an experimental rate constant, K_T, and rewritten as:

$$\frac{L_e}{L_a} = \exp\left[-K_T A_p^a Q_v^{-b}\right] \qquad \text{[Eq 11]}$$

where:

K_T = rate constant, m/d

A_p = specific surface area, m^2/m^3

Q_v = volumetric flow rate, m^3/m^3 day

a and b are experimental constants. The equation is very similar to Eq 5.

$$\frac{d^2S}{dz^2} = \frac{k\ S\ x}{D_c\ (S+k_s)} \qquad \text{[Eq 12]}$$[15]

where:

S = is the rate-limiting substrate concentration within the biofilm cellular matrix

z = depth of biofilm

k = maximum utilization rate of the rate-limiting substrate, mg/day-mg

x = bacterial concentration within the biofilm, assumed to be constant with depth, mg/L

D_c = diffusion coefficient within the biofilm, cm^2/day

k_s = half-velocity constant.

This equation does not possess an explicit solution, but may be used to describe the utilization rate of any substrate by a biofilm if that substrate is both flux- and substrate-limiting.

Although numerous design equations are available from the literature, the useful ones are limited to a few. There is very little information on the rate constants of the diffusion models, which makes them impractical for use. Group 1 and 3 equations are too simplistic. Group 2 equations can only be applied to situations for which they were specifically developed. Group 4 equations do not have any of these shortcomings and are therefore more widely used by design engineers today, notably Eq 5 (with m = 1.0 and n = 0.5).

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[15] K. Williamson, and P. L. McCarty, "Verification Studies of the Biofilm Model for Bacterial Substrate Utilization," J. WPCF, Vol 48 (1976), pp 281-296.

$$\frac{L_e}{L_o} = \exp\ [-KD/q^{0.5}]$$

is used exclusively by the manufacturers of plastic media. Table 14 summarizes the applicability of several trickling-filter design formulations.

Reliability of Plastic Media

The plastic material used in the media must be considered carefully, because not all plastic materials are equally resistant to chemicals. Thus, care should be taken if any chemical wastes are present to be sure that the material used is resistant to all of the waste components, because if the incorrect material is used, the media may disintegrate and fail.

The structural characteristics of plastics vary. Certain plastics such as saran and polyvinyl chlorides present difficulties with injection molding and must therefore be attached with adhesive or heat welding, which lack structural strength. Although not documented anywhere in the literature, randomly filled plastic ring media have reportedly settled in a few trickling filters. It is not known if the settlement is a natural phenomenon or the result of some collapsing of the ring structure at the bottom. However, from the literature, no shallow trickling filters with a bed depth of 6 ft or less using random fill plastic rings have experienced plugging problems due to the media.

The modular self-supporting units are structurally much stronger. Many installations are high towers more than 20 ft deep and have not experienced any structural problems. In general the minimum strength of the plastic material reported is 300 lb/sq ft. Design engineers can specify strength. None of the installations with tall plastic filter towers surveyed or visited

Table 14

Applicability of Trickling Filter Design Formulations

Formula	Stone Media	Synthetic Media	Domestic Wastewater	Industrial Wastewater	Temperature Correction Included	Experimental Work Required	Recirculation	Without Recirculation
NRC	A	NA	A	NA	NA	NA	NA	A
Ten States Standards	A	NA	A	NA	NA	NA	NA	A
Velz	A	A	A	A	NA	A	NA	A
Schulze	NA	A	A	A	NA	A	G	G
Germain	NA	A	A	A	NA	A	A	A
Eckenfelder	A	A	A	A	NA	A	A	A
Galler & Gotaas	A	NA	A	NA	A	NA	A	NA

Legend: A = applicable; NA = not applicable; and G = generalization not possible

had any structural problems, and many of them are the earliest plastic filters installed in this country. Table 15 outlines the characteristics of these installations.

Table 16 shows the seven randomly filled, plastic-media trickling-filter installations surveyed or visited. Each reported some settling of the media, ranging from a few inches in the shallower filters to a couple of feet in the taller towers. This settling will continue through the life of the project. All of the installations reported good BOD_5 removal. Only one reported an operational or maintenance problem associated with the media. The RCA plant in Mountaintop, PA, experienced a plugging problem, which was caused by the treatment used for the acidic waste.

Mixing qualities are good for the modular and the random-fill filters; recent changes are the sheet media industry's development of improved cross-flow capabilities which ensure mixing quickly. This counteracts the advantage held by randomly dumped media in shallow filters. Flow-through velocity is slower in random media, and may result in biomass buildups from sloughing activities, thus creating a condition prone to ponding. Sheet media have another advantage, in that media of different strengths and characteristics can be stacked in the same tower.

Other liabilities of randomly dumped media are that they should not be used when screening is the only pretreatment. Also, the compressive strength of dumped media is generally less than that of sheet media. Random media have more resistance to airflow, which may require forced ventilation.

In choosing a medium, several factors besides cost must be considered:

1. At least 10 percent more medium will be required for random dumping, resulting in extra work and inconvenient installation. Storage may also be a problem.

2. Randomly dumped media require grating underneath (i.e., aluminum bar grating), adding to the expense; sheet media rests on 2-ft centered concrete beams. Corrosion of metals from hydrogen sulfide is a potential problem underneath.

3. Grating is required on the top for random media to supply access to the distribution arm.

4. The trickling-filter structure must be much stronger for randomly dumped media to support weight (media and biomass) pressing outward. Sheet media support their mass and press downward, requiring a lower level of support on the periphery.

When the wastewater contains industrial discharges, it is advisable to consult the plastic media manufacturers about the chemical resistance of their material.

Table 15

Installations With Tall Plastic Filter Towers

Plant	Filter bed Depth (ft)	Age	Treatment Objective
Waste Treatment Plant Phoenixville, PA	21.5	15 yrs	Secondary Treatment Removal
McClellan Air Force Base Sacramento, CA	20.0	Since 1974	Secondary Treatment
Morton Frozen Foods, Crozet, VA	20.0 20.0	Since 1962 Since 1970	Secondary Treatment; 85% BOD_5 Removal
City of New Providence, NJ	14.4	Since 1970	Secondary Treatment; 90% BOD_5 Removal
Ambler Sewage Treatment Plant Ambler, PA	21.5	Since 1981	Secondary Treatment; 90% BOD_5 Removal
Lebanon Sewage Treatment Plant Lebanon, PA	21.5	Since 1980	Secondary Treatment; 80% BOD_5 Removal
Fort Lewis, WA	21.5	Since 1975	Secondary Treatment; 85% BOD_5 Removal

Table 16

Installation With Randomly Filled, Plastic-Media Filters

Plant	Filter bed Depth (ft)	Age	Treatment Objective
Alcoa Lafayette, IN	6 ft Conversion from Rock	Since 1974	Secondary Treatment; 65% BOD_5 Removal
U.S. Gypsum Oakfield, NY	5 ft Conversion from rock	Since 1975	Secondary Treatment; 65% BOD_5 removal
A.E. Staley Co. Lafayette, IN	9 ft	Since 1978	Roughing Filter; 45 to 50% BOD_5 Removal
USMC Station Paris Island, SC	16 ft	Since 1979	Secondary Treatment; 88% BOD_5 Removal
Newcomerstown WWTP, Newcomerstown, OH	20 ft	Since 1979	Secondary Treatment; 90% BOD_5 Removal
Gretna WWTP Gretna, LA	14 ft	Since 1978	Secondary Treatment
RCA Corp. Mountaintop, PA	6 ft Conversion from rock	Since 1975	Secondary Treatment

Cost of Trickling Filter Construction or Renovation

When the most widely used design equation for trickling filters is examined, i.e.,

$$\frac{L_e}{L_o} = \exp\left[-KD/q^{0.5}\right]$$

it can be seen that a deep filter will produce a superior effluent with a lower BOD_5 concentration. That is, for a given influent flow rate, a deep filter will be more efficient than a shallower filter of the same filter bed volume. By rearranging the equation in the following manner,

$$q^{0.5} = \frac{-KD}{\ln \frac{L_e}{L_o}} \qquad \text{[Eq 13]}$$

one can see that for the same k-rate and a specified BOD_5 removal, a 20-ft-deep filter will have a hydraulic rate (q in gpm/sq ft) four times as great as that of a 10-ft filter. In other words, a filter 20 ft deep would require only half as much volume of filter media to accomplish an equivalent BOD_5 removal as would a filter 10 ft deep.

To take advantage of the higher efficiency of a deep filter, the plastic medium is most useful. Because of their lightweight and self-supporting properties, plastic media can be contained in an inexpensive, lightweight tower. Although plastic media are more expensive than rock media, the cost is more than compensated for by the savings in tower construction costs and by the reduction of the bed volume requirement. When a shallow filter is constructed or when the conventional rock medium in a shallow bed is replaced with a plastic one, the BOD_5 removal will be limited by the medium's depth. The cost effectiveness of each option must be weighed as well as the predicted BOD_5 removal.

Construction or renovation costs should be estimated on a project basis. It is difficult, if not impossible, to make generalized comparisons because of the variability in cost-component innovations in design and because of the differences in the effluent quality required at each site.

J. E. Germain gives a cost comparison of a typical 10 mgd (37 850 m^3/day) domestic sewage treatment plant (Table 17).[16] The costs were for estimates of a conventional rock filtering plant and a plastic-media filtering plant.

All prices except that of the plastic-medium filters were based on bid prices of a similar midwestern two-stage trickling filter plant less than 2 years old. The estimates for the plastic-medium filters were based on average manufacturers' bid prices for plastic media, and on bid prices for the concrete and miscellaneous materials needed to construct the filter units.

Although the cost savings on the trickling filter units are only 10 percent, the savings in the entire treatment facility would be 21 percent due to elimination of the intermediate clarifiers and considerable simplification and shortening of the yard piping. Operating costs would be nearly identical for the two plants, with shorter pumping distances tending to favor the overall horsepower of the plastic-medium filter plant by a small margin, in spite of the increased depth of the medium.

A similar cost comparison is presented by Surfpac[17] (Table 18). In both cases, plastic-media filters prove to be more economical to use. However, it is not known if the cost of a forced aeration system, which is normally required in tall filter tower installations, is included in the estimate. Forced aeration is generally a function of the local climate.

[16] J. E. Germain, "Economic Treatment of Domestic Waste by Plastic-Medium Trickling Filters," JWPCF, Vol 38 (1966), pp 192-203.

[17] Plastic Media Biological Contact Processes, Surfpac Bulletin SBCT-11-3K82 (American Surfpac).

Table 17

Cost Estimate, 10-mgd Domestic
Wastewater Treatment Plant

(From J. E. Germain, 1966.)

Item	Rock Trickling Filter Plant ($)	Plastic-Medium Filter Plant ($)
Primary clarifiers	275,000	275,000
First-stage filters	305,000	270,000
Intermediate clarifiers	215,000	---
Second-stage filters	305,000	275,000
Secondary clarifier	275,000	275,000
Dry pit recirculation pump station	150,000	165,000
Yard piping	290,000	180,000
Site preparation	120,000	90,000
Total	1,935,000	1,530,000

Table 18

Economic Evaluation
of Rock Media and Plastic Media/1967

(From Plastic Media Biological Contact Processes.)

	Rock Media	Plastic Media
New Units Required	14	2
Size of Units (diameter) in feet	135	122
Depth of Media in feet	6	21
Volume of Media, cubic feet	1,219,000	506,000
Design Loading (lbs per 1,000 cf)	50	157
% Removal Design	66	61
% Removal Anticipated	66	78
Minimum Land Area Required, acres	8.7	0.9
Total Cost (excluding land)	$1,846,000	$1,577,000

Operations and Maintenance Requirements

The operations and maintenance changes between a rock trickling filter and a plastic-medium trickling filter are minimal, since the same process is used. However, tall towers with plastic media usually require forced aeration, while shallow rock filters do not.

Comparisons of the operations and maintenance requirements between a trickling filter and other treatment processes such as activated sludge are more substantial. For example, fewer operators are required at a trickling-filter plant than at an activated sludge plant because of its simpler operation. Also, the operators at a trickling filter plant do not need as much knowledge about the equipment because of the fewer possible malfunctions and fewer process monitoring requirements (see Table 19).

In general, operating costs for a trickling-filter plant will be less than for an activated-sludge facility. A major factor contributing to lower costs is manpower requirements. In general, 11 to 12 percent less manpower is required at a trickling-filter facility as compared to an activated-sludge facility. The power requirements are also usually less for a trickling-filter plant, because generally, the power required to aerate activated sludge is greater than the power required to pump the wastewater through a trickling filter.

New Developments and Applications of Plastic Media

B. F. Goodrich has recently introduced a new multiflow medium which is designed to obtain a longer retention time per unit depth than other plastic media. It is specifically for use in shallow filters and is ideal for replacing stones in a conventional trickling filter.

A new concept that can use plastic media trickling filters is the Trickling Filter/Solids Contact process, which couples the trickling filter with an aerated channel. Norris, et al.,[18] stated that "with the addition of solids-contact clarification, trickling filters can achieve the same effluent quality as the activated sludge process."

The process uses solids-contact clarifiers for superior suspended solids removal from wastewater treated by trickling filters. Sludge is recirculated to an aerated channel ahead of the clarifiers to develop a mixed liquor that enhances solids contact. The secondary sedimentation tank has center wells with mechanical flocculators that provide a mild stirring action to help flocculate the solids.

Research conducted at the Corvallis, OR, wastewater treatment plant has shown that conventional trickling filters can achieve both secondary treatment (monthly BOD_5 and Suspended Solids [SS] less than 30 mg/L) and advanced waste treatment (monthly BOD_5 and SS less than 10 mg/L) with relatively simple

[18]D. P. Norris, et al., "High Quality Trickling Filter Effluent Without Tertiary Treatment," JWPCF, Vol 54 (1982), pp 1087-1098.

Table 19

Operators Required per Plant as a Function of Flow Capacity

(From D. F. Kincannon, et al., "Trickling Filter Versus Activated Sludge, When to Select Each Process," Purdue Ind. Waste Conf. 28 [1973], pp 69-75.)

	Average Flow				
	1 mgd	5 mgd	10 mgd	50 mgd	100 mgd
Trickling Filter	6-7	9.5-11.5	13-16	37-44	63.5-76.5
Activated Sludge	7-8	11.5-13	15-18	43-49	71-82

design modifications of the secondary sedimentation process called the trickling filter/solids contact (TF/SC) process.

TF/SC Process

The TF/SC process, under development since 1979, has not been patented, which has encouraged its implementation. Several new plants have been finished, with many more in various design or construction phases.

Biological treatment is the basic process in nearly all military wastewater treatment plants, with most using trickling filters as the main means of reducing BOD_5 and suspended solids. The TF/SC process can be used at these plants for both upgrade and new construction, although the principles can also be adapted to suspended growth (activated sludge) and attached growth (RBC) plants to improve their effluent quality.

With minor modification, the TF/SC process incorporates the advantages of trickling filters to produce advanced level treatment for upgrading existing plants or for new construction. The desired upgrade level and effluent quality must be considered in design calculations, since they affect the needed modifications.

The TF/SC process is based on trickling filtration of primary effluent. The effluent enters an aerated solids contact channel, where it is mixed with sludge from the secondary sedimentation tanks to develop a mixed liquor which enhances solids contact. The concept's key is this use of sludge recirculation and aeration, coupled with solids contact clarifiers to provide excellent solids removal.

The solids-contact clarifiers used as secondary sedimentation tanks are similar to the conventional sludge suction secondary clarifiers used with the activated sludge process, but with the added feature of a flocculation center well that provides a mildly stirred environment for the entering mixed liquor. The mild stirring promotes agglomeration of fine, hard-to-settle solids into heavy floc that settles very quickly. Components of the process are presented in the following discussion.

The trickling filters can be the existing ones, new construction, or plastic media upgrades, as discussed earlier. TF/SC aerated solids contact channel serves the dual purposes of (1) promoting solids flocculation by increasing contact between the finely divided biological floc in the trickling filter effluent with the biological solids in the sludge returned from the secondary clarifier and, (2) providing a small but important amount of soluble BOD_5 removal. As reflected in the design criteria presented on pp 56-57 for the solids contact channel, the channel aeration should be limited to provide gentle mixing. If mixing is too vigorous, breakup of settleable floc occurs. Experience with the TF/SC process shows that some breakup of settleable floc occurs at channel aeration rates as low as 1.5 cu ft/min/ft of channel. Sludge return to the aerated contact channel is controlled to produce a mixed liquor solids concentration in the range of 500 to 1500 mg/L. Below this range, effluent quality is degraded because opportunities for solids contact decline. Above this range, effluent solids increase as more solids are processed by the secondary clarifiers. Essentially, as mixed liquor concentrations rise, the effluent solids level rises, because mixed liquor is removed at relatively constant efficiency.

The secondary clarifiers are critical to the success of the TF/SC process. Some TF/SC designs typically incorporate the following key features:

1. Clarifier sidewater depth of 16 to 20 ft.

2. Clarifier overflow rates of generally less than 600 gal/sq ft/day at average dry-weather flow (ADWF) and 1500 gal/sq ft/day at peak wet-weather flow (PWWF).

3. Weir placement at an in-board location to avoid solids carryover due to density current action.

4. Use of a flocculation chamber for inlet-induced gentle hydraulic stirring to incorporate of finely divided material into the biological floc, thereby improving clarification. A 20-minute hydraulic detention time is typical.

5. Sludge removal through submerged suction pickup rather than scraper-type mechanisms, although in some cases of 30/30, normal scraper-type mechanisms can be used.

Unlike the other two biological treatment processes presented in this evaluation, the TF/SC process produces an exceptionally dense sludge which can be discharged directly to the primary clarifiers without a separate sludge thickening step. It was found at Corvallis that cosettling raw sewage solids and waste trickling filter solids produced combined sludge concentrations of 5.5 to 6.5 percent while combined sludge from a conventional activated sludge process could be thickened to only 2.5 percent. This eliminates the sludge thickening step required in processes such as activated sludge or RBCs.

Trickling Filter/Solids Contact Process Design

To determine the TF/SC system size, the designer needs to know (1) filter media volume, (2) solids contact channel size and aeration rate, and (3) size of the secondary clarifiers.

The trickling filter media volume requirements can be estimated using the Schulze equation:

$$\frac{L_e}{L_o} = e^{\frac{-K_{20}\theta\, D}{Q^{0.5}}} \qquad \text{[Eq 14]}$$

or

$$\ln \frac{L_e}{L_o} = \frac{-K_{20}\theta\, D}{Q^{0.5}} \qquad \text{[Eq 15]}$$

where:

L_e = BOD_5 of secondary clarified effluent, mg/L

L_o = BOD_5 of bio-oxidation influent, mg/L

K_{20} = Wastewater treatability factor at 20°C

θ = Wastewater temperature correction factor

D = Media depth in feet

Q = Raw hydraulic flow rate, gal/min/sq ft.

Using this equation, the values of D, Le, Lo, K_{20}, and θ are set and the equation solved for Q. Plant raw influent flow rate is then divided by Q to establish media top surface area and multiplied by D to calculate media volume. Similar methods discussed earlier in this chapter can also be used. The trickling filter can be designed with Le at 30 to 35 mg/L.

Sizing of the solids contact channel requires estimation of the filter effluent soluble BOD_5. The channel volume is then established to provide contact time sufficient to reduce the soluble BOD_5 to the level desired in the final effluent.

This trickling filter effluent soluble BOD_5 calculation is based on the Velz equation and requires assumptions as to: (1) the soluble BOD_5 concentration (S_i) in the trickling filter feed prior to dilution with recycle, (2) the recycle ratio (R) defined as the recycle flow rate divided by the feed flow rate, (3) the wastewater temperature (T), and (4) the trickling filter hydraulic feed flux (Q_i) defined as the flow from primary sedimentation

divided by the cross-sectional area of the trickling filter. The modified Velz equation used follows:

$$S_e = \frac{S_i}{[R+1]\, e^{\frac{K_{20}\, A_s\, D\, \Theta^{(T-20)}}{[Q_i\ (R+1)]^n}} - R} \qquad \text{[Eq 16]}$$

where:

S_e = Soluble BOD_5 concentration in the trickling filter underflow, mg/L

S_i = Soluble BOD_5 concentration in the trickling filter feed, mg/L

R = Recycle ratio, gpm/gpm

A_s = Average media specific surface, sq ft/cu ft

T = Wastewater temperature, °C

Q_i = Trickling filter hydraulic feed flux, gal/min/sq ft

n = Flow exponent, dimensionless.

Key assumptions in establishing the solids contact channel size, in addition to the filter effluent soluble BOD_5 and the plant ADWF are: (1) the desired final effluent soluble BOD_5, (2) the mixed liquor volatile suspended solids concentration, and (3) the BOD_5 removal rate in the aerated channel, expressed as grams of BOD_5 removed per gram of mixed liquor volatile suspended solids per day.

An example of the air supply for a solids contact channel aeration system is a coarse-bubble system sized to provide enough dissolved oxygen in the channel to maintain an aerobic condition in the mixed liquor, but simultaneously limiting air input to produce only gentle mixing and avoid breakup of the settleable floc. Key assumptions in sizing the channel aeration system are: (1) the oxygen uptake rate of the mixed liquor, and (2) the oxygen transfer efficiency. Testing of the TF/SC process at Corvallis, OR, provided the basis for the oxygen uptake rate used in the aeration system sizing. The oxygen transfer efficiency assumed is 6 percent.

The trickling filter biological floc produced by the TF/SC process is separated in secondary flocculator clarifiers. Flocculation chamber size is based on a 20-minute hydraulic detention time. Sludge collection equipment is the submerged rapid sludge withdrawal type when possible.

TF/SC Costs

Since the TF/SC process requires secondary clarifiers with a separate flocculation well, secondary sedimentation cost is greater than for the competing processes. The RBC process exhibits the lowest cost for secondary clarifiers because the process only requires shallow (10 ft side water depth), conventional sludge scraper-type tanks.

Economic evaluation of alternative treatment systems requires consideration of annual costs as well as capital expenditures (project costs). Annual costs include operation and maintenance, depreciation, and interest rates on capital expenditures.

Operation and maintenance expenses include all costs for labor, energy, materials and supplies, and chemicals chargeable to various system components. Electricity purchased from the local public utility was assumed to cost \$.05 per kilowatt hour (kWh), and chemicals were priced at \$240 per ton for chlorine delivered and \$2 per pound for polymer delivered.

The interest on capital and depreciation of structures and equipment are commonly referred to as "fixed costs." A part of the annual costs of a facility includes the capital cost amortized over its economic life. In accordance with USEPA guidelines, the economic life of land, pipelines, structures, and equipment used in this report were:

Land	Permanent
Pipelines	50 years
Structure	40 years
Equipment	20 years

Under a contract from the B. F. Goodrich Company, Brown and Caldwell Consulting Engineers did an engineering-economic comparison of the TF/SC process to conventional technology (activated sludge and Rotating Biological Contactor [RBC]). Table 20 is an economic comparison of total project cost which shows the TF/SC process to be the least costly alternative. The table summarizes the results of the economic comparison of total project costs for the three alternative treatment systems. Based on total project costs, the TF/SC is shown clearly to be the least costly alternative, followed by the rotating biological contactor process and the activated sludge process. Table 21 is an energy comparison which shows that the TF/SC uses the least energy.

Table 22 provides an economic comparison of the estimated present worth of O&M costs for the three alternatives. The cost for energy shown is the net requirement for purchased power in terms of electricity and waste heat. The TF/SC process was found to have a substantially lower total annual O&M cost compared to the other alternatives. The TF/SC process provides a 61 percent and 33 percent reduction in total annual cost compared to the activated sludge and rotating biological contactor processes, respectively. This is a key benefit of the TF/SC process, especially for operating agencies hard-pressed to meet ever-increasing O&M budgets.

Since the varying relationships between annual costs, capital expenditures, and project staging often result in one plan being economically more attractive than another, the true economic value of a project can best be expressed in terms of present worth. The present worth of an alternative plan represents the long-term financial requirements of time-related projects and is the sum of the present worth capital expenditures and annual O&M costs over the planning period. It represents the cost savings realized from delaying the construction and operation of a project and, hence, capital expenditures.

Table 23 compares the cost-effectiveness of alternatives. It is evident that the TF/SC process shows the lowest total present worth cost for a 20-year

Table 20

Economic Comparison of Total Project Costs

(Engineering-Economic Comparison of the Trickling Filter/Solids Contact Process to Conventional Technology [Brown and Caldwell Consulting Engineers] April 1981.)

Item	Estimated Cost* (thousands of dollars) Trickling Filter/Solids Contact Process	Activated Sludge Process	Rotating Biological Contactor Process
Preliminary treatment	1,100	1,100	1,100
Primary treatment	2,330	2,330	2,330
Trickling filter circulation pumping station	420	---	---
Trickling filters	2,100	---	---
Solids contact channel	520	---	---
Aeration basins	---	4,500	---
Rotating biological contactor reactors	---	---	4,520
Flocculator clarifiers	2,000	---	---
Conventional secondary clarifiers	---	1,770	1,500
Dual-media filtration	---	1,500	1,500
Disinfection	2,040	2,040	2,040
Dissolved air flotation thickeners	---	390	---
Gravity thickeners	---	---	500
Anaerobic digesters	2,220	2,220	2,220
Facultative sludge lagoons and land application of sludge	830	830	830
Energy recovery facilities (including sludge gas engine generator and waste heat equipment)	320	320	320
Sitework	300	300	300
Administration, operations, and maintenance buildings	2,800	2,800	2,800
Outside piping	1,900	1,900	1,900
Subtotal, construction cost	18,880	22,000	21,860
Engineering, administration, legal, fiscal, and contingencies at 35 percent	6,580	7,700	7,650
Subtotal, project cost exclusive of land	25,460	29,700	29,510
Land	260	265	255
Total project cost	25,720	29,965	29,765

*Costs based on ENR-CCI value of 3500.

Table 21

Energy Comparison of Alternatives--Total Plant Basis

(Brown and Caldwell, 1981)

Item	Estimated Energy Requirements (1000 kWh/yr)		
	Trickling Filter/Solids Contact Process	Activated Sludge Process	Rotating Biological Contactor Process
Preliminary treatment	70	70	70
Primary treatment	25	25	25
Secondary biological process	1,080	1,650	1,940
Dual-media filtration	*	550	550
Effluent disinfection	55	55	55
Sludge thickening	**	280	10
Anaerobic digestion	1,500	1,550	1,550
Facultative sludge lagoons and land application of sludge	55	55	55
Energy recovery	125	125	125
Building and digestion heating and cooling+,++	300	550	200
Subtotal	3,210	4,910	4,580
Estimated equivalent energy available from energy recovery facilities	-1,450	-1,450	-1,450
New total estimated energy usage	1,760	3,460	3,130

*Not required.
**Waste sludge thickening in primary clarifiers.
+For northern U.S. locations.
++Net demand.

Table 22

Economic Comparison of Estimated Present Worth of Operation and Maintenance Costs

(Brown and Caldwell, 1981.)

Item	Estimated Annual costs, Thousands of Dollars: Trickling Filter/Solids Contact Process	Activated Sludge Process	Rotating Biological Contactor Process
Labor	257	381	332
Energy	88	173	157
Materials and supplies	26	38	33
Chemicals	47	62	47
Total operation and maintenance cost	418	654	569
Total present worth cost[a,b]	4,386	6,862	5,971

[a]Based on ENR-CCI value of 3500.
[b]20-year analysis at 7-1/8 percent interest.

Table 23

Cost-Effective Comparison of Alternatives

(Brown and Caldwell, 1981.)

Item	Estimated Annual Costs, Thousands of Dollars: Trickling Filter/Solids Contact Process	Activated Sludge Process	Rotating Biological Contactor Process
Total present worth project cost	25,720	29,965	29,765
Total present worth of operation and maintenance costs[a,b]	4,386	6,862	5,971
Total present worth cost	30,106	36,827	35,736

[a]Based on ENR-CCI value of 3500.
[b]20-year analysis at 7-1/8 percent interest.

planning analysis at 7-1/8 percent interest for a 10-million gal/day treatment plant. The primary reasons for the cost-effectiveness superiority of TF/SC are:

1. Monthly average BOD_5 and suspended solids of 10 mg/L or less are attainable without effluent filtration.

2. Soluble BOD_5 reduction in the solids contact channel, beyond that which can normally be expected from the trickling filters, provides a cost-effective means of meeting effluent requirements.

3. Waste biological sludge from the TF/SC process is dense enough for efficient wasting directly to the primary clarifiers for co-settling with the primary sludge. This eliminates the need for a separate sludge-thickening step in the treatment train.

4. Sludge yields in the TF/SC process are comparable to those of competing conventional technology; thus, associated sludge-handling and treatment costs are comparable.

5. The TF/SC process is a stable, relatively simple system requiring far less equipment, electrical control, and operator attention than competing conventional technology, so the total O&M costs are substantially lower.

6. The TF/SC process consumes less than half of the estimated annual energy demand of competing conventional technology because of its lower overall horsepower requirements. Reduced sludge recycle compared to the activated-sludge process is significant.

The new regional sewage treatment plant involving Fort Stewart and Hinesville in Georgia will use the TF/SC process. The plant will have two-stage trickling filters with contact aeration and should produce an excellent effluent. The unit processes are: primary treatment, grit chamber, trickling filter, aerated contact basin, secondary clarifier, second trickling filter I. for nitrification, aeration, and chlorine contact. The effluent BOD_5 and suspended solids requirements are 10 mg/L.

5 SITE VISITS--PLASTIC-MEDIA TRICKLING FILTER PLANTS

Several site visits were conducted to inspect the trickling-filter plants using plastic media. Two U.S. Army facilities, a municipal treatment plant, and an industrial facility were visited:

1. Sewage Treatment Plant #4
   Seneca Army Depot
   Romulus, NY

2. Sewage Treatment Plant
   Fort Lewis, WA

3. Suffern Municipal Sewage Treatment Plant
   Suffern, NY

4. Sewage Treatment Plant
   RCA Corporation
   Mountaintop, PA

Seneca Army Depot Sewage Treatment Plant (STP) #4

This sewage treatment plant was constructed in 1942 and has since undergone several modifications and upgrades. It has a design capacity of 0.25 mgd and was originally equipped with a rock filter 50 ft in diameter and a 3-ft bed depth. Before modification in 1980, STP #4 consisted of a bar screen, a final clarifier, a sludge-drying bed, and a chlorine contact chamber which was not in use. The plant layout currently used (see Figure 5) is the same as it was before the modifications in 1980.

Part of the Seneca Army Depot wastewater is joined by wastewater from the City of Romulus by gravity into an open channel at the head of STP #4. The combined wastewater passes through a bar screen and into the influent wet well. The wastewater is then pumped from the wet well by one of two 450-gpm (28.4 L/s) pumps to the Imhoff Tank, a dual-chambered unit with no skimmer for grease and scum removal. The Imhoff Tank effluent flows by gravity to the trickling filter. About 0.59 mgd of effluent return flow returns to the influent wet well by gravity. The final clarifiers are two rectangular units operated in parallel. No sludge collection or scum-skimming mechanisms are provided for the final clarifiers. Sludge is removed by draining and pumping. The final clarifier effluent passes through a 6-in. Parshall flume and into the chlorine contact chamber. Chlorine is not required by the NPDES permit, so none is added. Table 24 shows the STP #4 influent wastewater characteristics.

Several modifications to the trickling filter at STP #4 have been made since 1980. These changes include installing an aluminum grating about 4 in. above the slanted filter floor, replacing the rock medium with a plastic medium, adding a new protective aluminum dome over the trickling filter, and replacing the bearings of the existing rotating arm distributor. Another change was to modify the recirculation pipe, which increases the recirculation flow to 0.59 mgd or a recirculation flow of 3.25, based on the average flow of only 0.18 mgd.

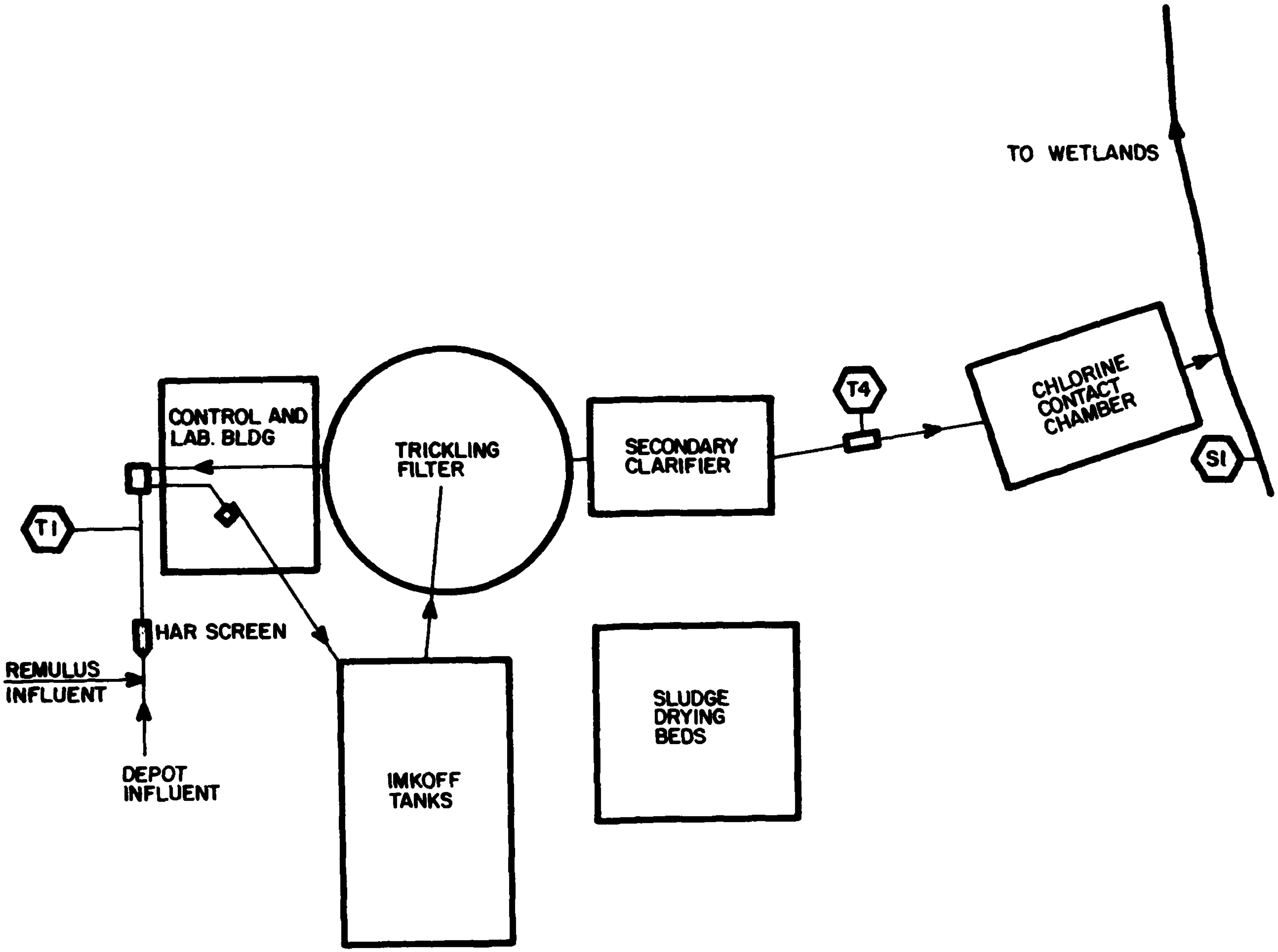


Figure 5. Layout and sampling sites of STP #4 at Seneca Army Depot, New York.

Table 24

STP #4 Influent Wastewater Characteristics

Characteristic*	High	Low	Mean
pH (standard units)	8.0	5.5	7.32
Conductivity (μmhos/cm)	2,222	133	1,348
Total Suspended Solids	352.0	5.0	99.95
Volatile Suspended Solids	200.0	3.0	68.06
BOD_5	316.0	8.6	97.40
BOD_5 Soluble	77.0	1.7	26.08
Total Phosphate	7.8	0.6	2.60
Ammonia Nitrogen	42.0	0.8	11.68
Total Kjeldahl Nitrogen	47.0	5.6	17.06
Total Coliforms (col/100 mls)	$1.4x10^8$	$2.4x10^3$	$9.27x10^6$
Fecal Coliforms (col/100 mls)	$2.0x10^7$	$2.4x10^2$	$1.52x10^6$
Dissolved Oxygen	10.1	1.0	4.11
Temperature (^oC)	21.0	3.0	11.65
Flow (gpd)	1,509,500	35,000	235,039

*mg/L unless otherwise noted

These modifications have greatly improved the efficiency of the treatment plant.[19] The effluent BOD_5 concentration has decreased since 1980, from 30 mg/L to 9 mg/L with the percent BOD_5 removal increasing from 58 to 93 percent. Table 25 shows the 7-day data points from 1980 and 1982 used to obtain this data. Table 26 shows the 7-day arithmetic means for selected characteristics, as well as 18 months of monitoring data for the plant's influent and effluent. This table also includes the percent removal for the same characteristics. Effluent total suspended solids (TSS) levels have decreased from 13 mg/L to 7 mg/L with percent TSS removal increasing from 84 to 94 percent. Effluent total Kjeldahl nitrogen (TKN) levels have decreased from 11 to 2.3, with percent removal increasing from 9 to 90 percent, and NH_3-N levels have decreased from 8.3 to 0.8, with percent removal increasing from 9 to 94 percent.

Table 27 summarizes the average influent, effluent, and percent removal of sewage characteristics for 18 months.[20] The average removal for the study period was 77 percent BOD_5, 86.6 percent TSS, 60 percent TKN, and 71.4 percent NH_3-N. Tables 28 and 29 show the 7-day arithmetic mean for BOD_5 and TSS. By comparison, the percent removal found in this study is not as significant as in the "before" and "after" study, because many more variations, such as

[19] Innovative Wetlands Wastewater Treatment Project Two-year Evaluation Seneca Army Depot, Romulus, New York, Water Quality Engineering Special Study No. 32-24-8861-83 (USAEHA, 19-30 July 1982).

[20] Second Study Innovative Wetlands Wastewater Treatment Project Sampling and Analysis Program Report, Seneca Army Depot, Romulus, NY, Contract No. DACA 51-79-C-0034 (Lozier Architects/Engineers, 1982).

Table 25

Data for STP #4 Before and After
Trickling Filter Renovation
(7-Day Data Points)
(From AEHA)

	1980			1982		
	Date (July 80)	STP Influent	No. 4 Effluent	Date (July 82)	STP Influent	No. 4 Effluent
BOD_5 mg/L	23	66	36	21	93	13
	24	43	31	22	x	x
	25	81	28	23	169	10
	26	74	26	24	136	8
	27	100	30	25	88	7
	28	91	31	26	127	6
	29	56	30	27	128	8
	Avg.	73	30.3	Avg.	124	9
TTS mg/L	23	150	18.5	21	63	3
	24	25	18	22	131	2
	25	153	14	23	156	8
	26	60	16	24	136	12
	27	61	9	25	78	17
	28	50	4	26	117	3
	29	99	15	27	117	7
	Avg.	85.4	13.4	Avg.	114	7
TKN mg/L	23	14	15	21	15	3.4
	24	12	14	22	23	2.8
	25	15	13	23	20	2.8
	26	12	10	24	27	1.8
	27	11	7.7	25	13	1.9
	28	13	9.3	26	29	1.6
	29	8.2	8.9	27	30	1.7
	Avg.	12.2	11.1	Avg.	22	2.3
NO_2NO_3-N mg/L	23	1.9	2.2	21	0.2	4.8
	24	2.2	2.5	22	0.01	6.5
	25	3.2	2.5	23	0.01	6.9
	26	2.9	3.5	24	0.06	x
	27	2.9	4.0	25	0.02	9.9
	28	1.7	3.2	26	0.04	9.6
	29	1.5	2.1	27	0.05	10
	Avg.	2.3	2.9	Avg.	0.06	8.0
NH_3-N mg/L	23	11	11	21	6.9	0.8
	24	9.6	9.5	22	7.7	0.7
	25	11	8.4	23	15.0	0.8
	26	7.6	7.7	24	7.7	0.5
	27	9.0	6.5	25	3.6	0.5
	28	9.7	7.3	26	20.0	0.8
	29	5.6	7.4	27	30.0	0.7
	Avg.	9.1	8.3	Avg.	13.0	0.8

Table 26

Summary of Data for STP #4
Before and After Trickling Filter Renovation
(7-Day Arithmetic Means)
(From Lozier)

(All values are arithmetic means of seven data points except 18-month monitoring.)

	INFLUENT			EFFLUENT		
	1980 Before	1982 After	18-Month Monitoring	1980 Before	1982 After	18-Month Monitoring
BOD_5 mg/L	73	124	97	30	9	18.3
TSS mg/L	85	114	100	13	7	12.9
TKN mg/L	12.2	22	17.1	11	2.3	6.9
NO_2-NO_3-N mg/L	2.3	0.03	---	2.9	8.0	---
NH_3-N mg/L	9.1	13.4	11.9	8.3	0.8	3.4

Table 27

Average Removal Over 18 Months at STP #4

	1980 Before	1982 After	18-Month Monitoring
BOD_5 %	58	93	77
TSS %	84	94	86.6
TKN %	9	90	60
NO_2-NO_3-N%	x	x	x
NH_3-N %	9	94	71.4

Table 28

Data Summary—Treatment Plant Performance for BOD_5
(From Lozier)

BOD_5
7-Day Arithmetic Mean

Sampling Point	High	Low	Mean	Std. Dev.	NPDES Permit Limitation	No. of Violations/ No. of Data Points
(T-4) STP#4 Effluent	45 mg/L	2.7 mg/L	18.0 mg/L	10.5	45 mg/L	0/48

BOD_5
30-Day Arithmetic Mean

Date	(T-1) STP #4 Influent (mg/L)	(T-4) STP #4 Effluent (mg/L)	% Removal
November (80)	43.0	12.0	72.1
December	49.5	10.6	78.6
January (81)	42.0	14.9	64.5
February	25.9	9.3	64.1
March	67.5	19.5	71.1
April	54.0	23.7	56.1
May	165.0	29.8	63.7
June	192.0	14.0	92.7
July	72.5	29.5	59.3
August	229.5	21.5	90.6
September	153.0	15.0	90.2
October	78.5	17.0	78.3
November	85.5	9.5	88.9
December	119.0	9.3	92.2
January (82)	74.0	15.0	79.7
February	118.0	24.8	79.0
March	121.0	14.7	87.9
April	95.8	22.8	76.2

Sampling Point	High	Low	Mean	Std. Dev.	NPDES Permit Limitation	No. of Violations/ No. of Data Points
(T-4) STP #4 Effluent	29.8 mg/L	9.3 mg/L	17.4 mg/L	6.65	30 mg/L	0/18
% Removal	92.7%	56.1%	77.0%	11.94	85%	12/18

Table 29

Data Summary--Treatment Plant Performance for TSS
(From Lozier)

TSS
7-Day Arithmetic Mean

Sampling Point	High	Low	Mean	Std. Dev.	NPDES Permit Limitation	No. of Violations No. of Data Points
(T-4) STP #4 Effluent	40 mg/L	1 mg/L	12.35 mg/L	10.10	45 mg/L	0/54

TSS
30-Day Arithmetic Mean

Date	(T-1) STP #4 Influent (mg/L)	(T-4) STP #4 Effluent (mg/L)	% Removal
November (80)	93.0	13.0	86.0
December	77.5	10.5	87.1
January (81)	55.2	9.2	83.3
February	39.0	5.5	85.9
March	146.5	24.3	83.4
April	43.4	11.4	73.7
May	102.5	24.2	76.4
June	105.4	16.3	84.5
July	278.0	12.5	95.5
August	278.0	12.5	95.5
September	176.3	7.2	95.9
October	89.5	20.0	77.7
November	96.3	7.5	92.2
December	77.3	8.0	89.7
January (82)	42.0	2.0	95.2
February	56.5	8.8	84.4
March	120.3	8.3	93.1
April	86.0	24.5	71.5

Sampling Point	High	Low	Mean	Std. Dev.	NPDES Permit Limitation	No. of Violations/ No. of Data Points
(T-4) STP #4 Effluent	24.5 mg/L	2.0 mg/L	12.43 mg/L	6.75	30 mg/L	0/18
% Removal	95.9%	71.5%	86.6%	7.3	85%	9/18

weather, organic loadings, and hydraulic loadings, are involved. Thus, both studies must be examined on their own merits.

STP #4 at the Seneca Army Depot uses 12 acres of wetlands as part of the plant. After this process, all NPDES permit requirements (typical of the requirements of a tertiary treatment plant) were met for the 18-month study (see Table 30).

The NPDES permits for the STP #4 for the secondary treatment portion only (excluding the wetlands) are:

BOD_5 7-day arithmetic mean	45 mg/L
30-day arithmetic mean	30 mg/L
85% removal	
TSS 7-day arithmetic mean	45 mg/L
30-day arithmetic mean	30 mg/L
85% removal	

It is noted that after the secondary treatment (by analyzing the samples taken at sampling point T4 shown in Figure 5), only the effluent concentration requirements were met. For the 85 percent BOD_5 removal limitation, the requirements were missed 12 times, or 67 percent of the time. Similarly, the requirement for 85 percent removal of TSS was missed 9 times, or 50 percent of the time. The cause of the violation of NPDES permits in percentage removal of BOD_5 and TSS is primarily due to inflow/infiltration (I/I) problems at the facility, and steps are being taken to correct the situation. In the past, I/I repeatedly diluted the BOD_5 and TSS in the influent. When the BOD_5 and TSS concentrations are very low, as shown in the influent wastewater characteristics table, it is impossible to remove 85 percent by any biological secondary treatment processes. The situation is not unique, since most secondary treatment plants in this country subject to I/I influence experience the same problem.

STP #4 at the Seneca Army Depot was originally scheduled to be rebuilt as an RBC plant at an estimated cost of $2.5 million. However, the plant was renovated instead, and the trickling filter with plastic media is working beyond expectation. With a shallow bed depth of only 3 ft, the process has upgraded the treatment performance so that it meets the effluent BOD_5 and TSS concentration requirements all the time. Thus, since plastic trickling filters with deeper beds have higher treatment efficiency, a rock filter with a typical bed depth of 6 to 8 ft can be upgraded even more successfully with the addition of plastic media. If, in the case of STP #4 at Seneca Army Depot, all units except the rock filter are working properly at the designed flow, renovation of the rock filter is the only modification required, and a substantial cost saving will be realized.

The difference between the new RBC plant cost and the trickling filter renovation cost does not necessarily represent all the potential cost savings. Chapter 6 provides more details on cost analysis.

Table 30

NPDES Permit Requirements for STP #4 *

Effluent Requirements

Discharge 001 - Building No. 4

Effluent Characteristics		mg/L	Discharge Load Allocations (lb/day)	Minimum Removal (lb/day)	Percent Limitations
5-day - 20°C Biochemical Oxygen Demand	Daily Maximum	5.0	10.4	4.7	85%
Suspended Solids	30-day arithmetic mean	10	20.8	9.5	85%
Suspended Solids	7-day arithmetic mean	20	41.6	19.0	85%
Dissolved Oxygen	Daily Minimum	7.9	N/A	N/A	N/A
Ammonia Nitrogen	Daily Maximum	2.0	N/A	N/A	N/A

*Extracted from NPDES Permit No. NY 0020296

Fort Lewis Sewage Treatment Plant

The sewage treatment plant at Fort Lewis receives inflows from both the base and a number of contiguous communities. The components of the Fort Lewis treatment plant input are:

Assigned military and civilian personnel
Family housing
Madigan Army Medical Center
Veterans hospital
Camp Murray
McChord Air Force Base
Town of Dupont

The plant was built in 1955 with a design capacity of 7 mgd, with capability for sedimentation, digestion of solids, and disinfection of the effluent. The plant was upgraded in 1975 to accommodate the increased flow and BOD_5 loadings to the plant (present flow fluctuates from 3 to 10 mgd daily) and the new water quality requirements imposed by the State of Washington. The scope of work of the treatment plant upgrading was to provide artificial-media trickling filters and an overall plant removal efficiency of 85 percent BOD_5 and 90 percent suspended solids at average loading conditions.

The design criteria for the plant modifications are:

Design population	70,000 persons
Average flow	7 mgd
Minimum flow	2.8 mgd
Maximum flow	15.0 mgd
BOD_5 (@ .35 ppcd)	24,500 lb/day
Suspended Solids (@ .35 ppcd)	24,500 lb/day

Plant Design

Figure 6 shows the process flow for the treatment plant before and after modification. In the new design, new headworks is constructed and the raw sewage conveyed through two mechanically raked bar screens to a 20-ft, detritor-type grit chamber. Screenings are removed by conveyor to a dumpster. The grit chamber removes minus-150-mesh grit at average flow. A grit chamber bypass is provided, and grit is washed by a cyclone-type separator/washer; organics are returned to the plant flow, and the washed grit is deposited in a dumpster for separate disposal. Grit chamber overflow will normally pass through two sewage shredders or will be bypassed through two 3-ft, manually raked bar screens. The raw waste then enters a flow division chamber where weirs proportion the flow to the existing primary clarifiers.

The two existing 24-in. lines are retained to carry the divided flow to the existing primary clarifiers. New influent baffles, influent port gates, and effluent weir plates are provided for the existing clarifiers. Manual, lever-operated type equipment removes scum, which is discharged to a scum pit; from here, the primary scum pump pumps it to either the sludge thickener or to the scum concentrator located at the Sludge Thickening Complex.

Primary effluent flows in a revised launder to a new primary effluent pump station having three pumps with capacities of 11 mgd, 11 mgd, and 5.9 mgd. An automatically operated butterfly valve will control the amount of trickling-filter effluent recirculation to the pump station.

Pumps are sized such that one 11-mgd pump will handle the average flow with 50 percent filter effluent recirculation. The 5.9-mgd pump will start automatically to meet the peak hydraulic flow and will operate until manually shut off by the operator. The remaining 11-mgd pump will act as a backup.

The pump discharge is evenly split between two new 80-ft-diameter trickling filters with 21.5-foot media depth. Each filter has two effluent channels at the one-third points and adjustable vent openings equivalent to 2 sq ft per 1000 cu ft of media.

Filter underflow goes to a splitter box and is divided between the two 90-ft-diameter secondary clarifiers and recirculated to the primary effluent pump station.

Clarifier effluent goes via a secondary bypass box (post chlorination point) to a splitter box where flow is evenly split between the existing chlorine contact chamber and a new 28-ft by 100-ft chlorine contact chamber. Provision is made for bypassing either of the chambers using slide gates. Gear-operated scum removal equipment is provided. The chlorinated effluent then enters the existing outfall line.

Solids Handling

Solids handling is as shown in Figure 7. Raw primary sludge will enter the existing sludge pit. Two vertical vortex-type sludge pumps with a capacity of 150 gpm each will discharge a thinner sludge (1 percent solids or less) to a new 45-ft-diameter sludge thickener. Provision is made to divert primary sludge via the new thickened sludge pump station directly to the primary digesters.

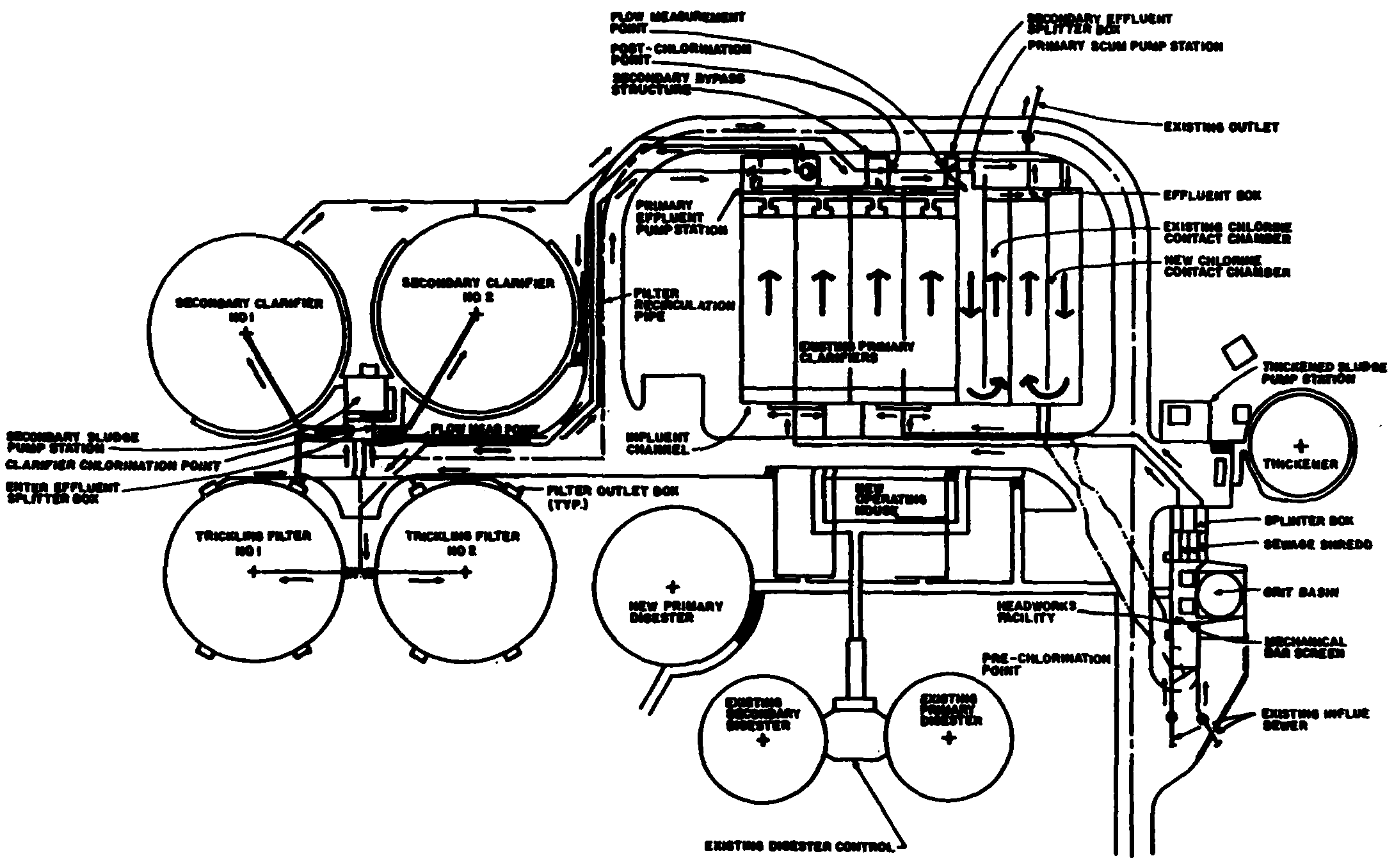


Figure 6. Fort Lewis sewage treatment plant, path of flow.

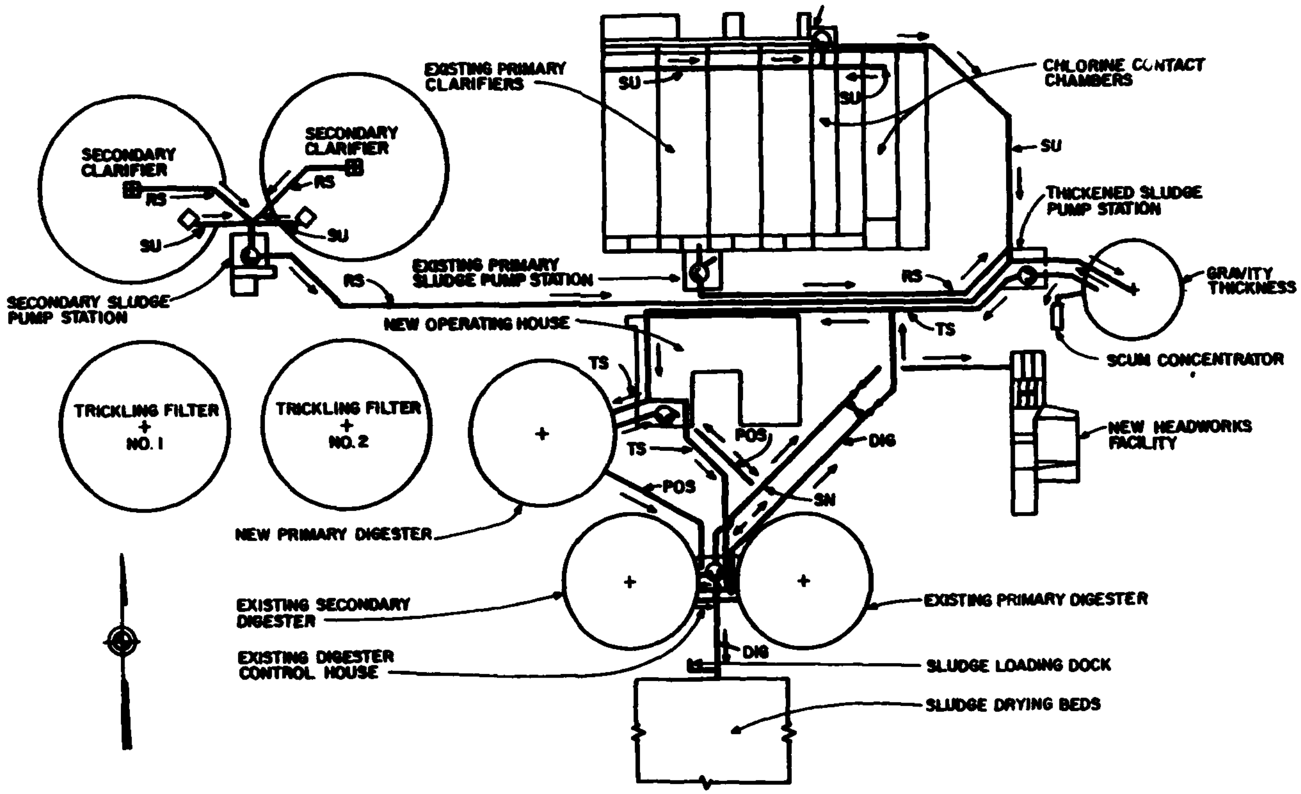


Figure 7. Fort Lewis sewage treatment plant, solids handling schematic.

Secondary sludge and scum are pumped to the thickener from a new secondary sludge pump station. Provision is made to divert secondary sludge to the headworks (via the thickened sludge pump station) for discharge to the primary clarifiers. Two 140-gpm sludge pumps and a 570-gpm dilution water pump are provided.

Scum from the sludge thickener goes to the scum concentrator and is then discharged to a dumpster; the supernatant is returned to the headworks.

Thickened primary and secondary sludge will be pumped through the thickened sludge pump station to one of two primary digesters. The existing primary digester has been provided with a new cover and gas mixing system, and a new 70-ft, fixed-cover primary digester with a similar mixing system has been added. Sludge heating is by circulation of primary digested sludge through external heat exchangers located in two separate digester control rooms. Secondary digestion uses the existing secondary digester. The primary digester may be used as a secondary tank if operating conditions require it. There is enough flexibility in the piping design to allow transfer of sludge between any combination of the units. The secondary digester has been provided with a new gas-holder cover.

Digested sludge from the secondary digester is then pumped to the existing sludge-drying beds; half of the beds have an open-sided cover. Provision is made for return of the digester supernatant to either the sludge thickener or to the headworks. The digested sludge can also be returned to the thickener, to the headworks, to either primary digester, or to a sludge loading dock, if necessary.

Operating House

The chlorine storage area has a cylinder storage capacity of 12 cylinders. New chlorine scales and a new hoist and monorail system are provided. A new 2000 lb/day chlorinator has been provided; the existing 2000 lb/day chlorinator is used as a backup unit.

Part of the operating house addition is devoted to thickened sludge pumping and heating and to digester recirculation. This same area contains a new boiler and heating system. Gas mixing equipment is located in a separate room which also contains the gas control and metering equipment. Present operations areas have been rearranged and a lunchroom, bacteriology lab, and office and control spaces have been added.

Monitoring and sampling capabilities have been increased with the addition of a plant control panel which meters plant flow and chlorine flow. The bacteriology lab provides an automatic sampling system for the influent, primary effluent, and chlorinated effluent.

Plant Capacity

The capacity of the modified treatment plant was recently analyzed based on the size of the treatment and mechanical units per construction specification, as well as an assumed population equivalent of 100 gpd flow, 0.17 lb BOD_5/day and 0.2 lb suspended solids/day (Table 31). As shown in Table 31, the plant can serve a population equivalent as large as 85,300 properly.

Table 31

Fort Lewis Sewage Treatment Plant Unit Capacity

Component	Determination of Capacity	Capacity: Average	Capacity: Peak
Bar screens, rakes, sewage shredders	Hydraulic capacity per construction specs 2 x 7.0 mgd = 14.0 mgd at peak	---	14 mgd
Grit chamber	Hydraulic capacity based on 1 fps at peak flow. 1 fps x 1.5 ft x 20 ft x 1440 x 7.48 = 19.4 mgd	---	19.4 mgd
Primary clarifiers	Hydraulic capacity based on gallons per square foot per day (gpsfpd) on overflow, rates 4 x 24 ft x 100 ft x 800 gpsfpd = 7.7 mgd @ ave. 4 x 24 ft x 100 ft x 1200 gpsfpd = 11.5 mgd @ peak	7.7	11.5 mgd
	Hydraulic capacity based on weir rates 4 x 73 ft x 20,000 gpsfpd = 5.0 mgs @ peak	---	5.0 mgd
Primary effluent	Hydraulic capacity based on capacity with largest pump out of service 2 @ 11 mgd, 1 @ 5.8 mgd; 11 + 5.8 = 16.8 mgd	---	16.8 mgd
Trickling filters	Hydraulic capacity of rotors without recycle per construction specs 2 x 7700 gpm x 1440 = 22.2 mgd	---	22.2 mgd
	BOD_5 loading capacity in population equivalents (assume primary clarifiers removed only 20 percent of BOD_5 from raw sewage due to hydraulic overload of primary clarifiers) $\dfrac{2\,(40.83\text{ ft})^2 \times 22.1\text{ ft} \times .050\,\dfrac{\text{lb } BOD_5 \text{ to filter}}{\text{cu ft day}}}{\dfrac{0.8\text{ lb } BOD_5 \text{ to filter}}{\text{lb } BOD_5 \text{ in raw sewage}} \times \dfrac{0.17\text{ lb } BOD_5 \text{ in raw sewage}}{\text{person day}}} =$	85,300 people	85,300 people
Secondary clarifier	Hydraulic capacity based on overflow rates $2\,(45\text{ ft})^2$ x 600 gpsfpd = 7.6 $2\,(45\text{ ft})^2$ x 1200 gpsfpd = 15.2 mgd	7.6	15.2 mgd
	Hydraulic capacity based on weir rates 2 x (2 40 + 2 38) x 15,000.gpsfpd = 14.7 mgd	---	14.7 mgd
Chlorinator	Dosage capacity based on construction specs $\dfrac{20000\text{ lb/day}}{10\text{ mg/L} \cdot 8.34} = 24\text{ mgd}$	---	24 mgd
Chlorine contact tank	Hydraulic capacity based on detention time (2 x 11' x 100.3' x 8' + 2 x 14' x 100.3' x 8') x 7.48 x 1440 = 14.4 mgd	---	14.4 mgd
Outfall	Hydraulic capacity based on maximum high water 6.4 ft above MLLW with last manhole surcharged to 25 ft above MLLW (i.e., just below manhole lid)	---	19.6 mgd
Sludge thickener	Sludge capacity in population equivalents $\dfrac{(22.5\text{ ft})^2}{0.2\,\dfrac{\text{lb solids}}{\text{person}}} \times 20\,\dfrac{\text{lb solids}}{\text{sq ft} \cdot \text{day}} = 79{,}500$		
Sludge digester	Digester capacity based on heating sludge to speed digestion, in population equivalents: Primary digester 70,780 cf Primary digester 111,606 cf Secondary digester 70,780 cf 253,166 cf [illegible] $\dfrac{\text{cu ft}}{\text{person}}$ = 63,000 people	---	63,000 people
Sludge-drying beds	Sludge capacity in population equivalents $\dfrac{24 \times 29.2\text{ ft} \times 100\text{ ft}}{1.0\,\dfrac{\text{sq ft}}{\text{person}}} = 70{,}000$ people	---	70,000 people

Population Equivalent = 100 gpcd
0.17 lb BOD_5/day
0.20 lb suspended solids/day

However an equalization basin should be added and the present sludge-drying beds should be expanded to avoid decreasing the treatment efficiency.

The design population for the modified treatment plant is 56,000 residents; the population actually served is 41,200 residents and 12,400 nonresidents (based on a November 1979 survey). Only 2 percent of the flow coming into the treatment plant is industrial in nature (e.g., as photographic shop waste, cooling water, laundry, and maintenance shop waste and some pesticides).

The present flow varies between 3 to 10 mgd, with an average of about 3.9 mgd. Before modification, the plant had to meet only the primary treatment plant performance standards, and there was no difficulty in doing that. However, the modified treatment plant meets the secondary treatment requirements imposed by the State of Washington. The monthly average influent BOD_5 of the sewage is 193 mg/L. The concentration is higher in the summer, varying between 200 to 400 mg/L; in the winter, the average BOD_5 concentration is only 130 mg/L because of excessive infiltration. The monthly average influent suspended solids concentration is 132 mg/L. Similarly, the concentration is higher in the summer, varying between 200 to 400 mg/L but lower in the winter (about 130 mg/L). The treatment plant has no problem meeting the NPDES permits for fecal coliform, 30 mg/L of BOD_5, and suspended solids. Percentages of BOD_5 and suspended solids removal are also met (an average of 86 percent suspended solids and 91 percent BOD_5 versus the 85 percent required), except during the winter time. Because of the lower concentration caused by infiltration, even an effluent concentration of 15 to 25 mg/L for BOD_5 and 15 to 22 mg/L for suspended solids would not meet the 85 percent removal requirements. This problem can be eliminated when the problem of stormwater infiltration is minimized or corrected.

The plant was built in 1955 at an estimated cost of $500,000. The modification cost in 1975 was about $3.5 million.

Suffern Wastewater Treatment Plant

This municipal wastewater treatment plant, located in Suffern, NY, has a design capacity of 1.9 mgd; its secondary treatment consists of two 40-ft-diameter trickling filters with rock filtering media followed by final clarification. Rock filters were converted to 6-ft-deep plastic-media filters to upgrade the treatment performance. The renovated filters will be used as roughing filters, with activated sludge treatment as the secondary treatment process.

Before the renovation, a pilot testing program to evaluate the BOD_5 removal capacity of the plastic filtering medium was conducted. After 6 months, it was found that the plastic medium had a much higher BOD_5 removal capacity than the rock medium. However, before the test program ended, the brand of medium being used was taken off the market, so a similar medium was selected for the renovation. A new filter drainage system was put in for each filter, using precast H-sections of concrete beams which provided a flat surface for the plastic modules. The 6-ft media depth was maintained, but the rotary distributor can be raised 2 to 3 ft so that more media can be added in the future if needed. Figures 8 through 16 show the various stages of the filter renovation work.

Figure 8. Original rock filter, Suffern Municipal Wastewater Treatment Plant.

Figure 9. Removal of filter wall and rock media.

Figure 10. Renovation of filter floor.

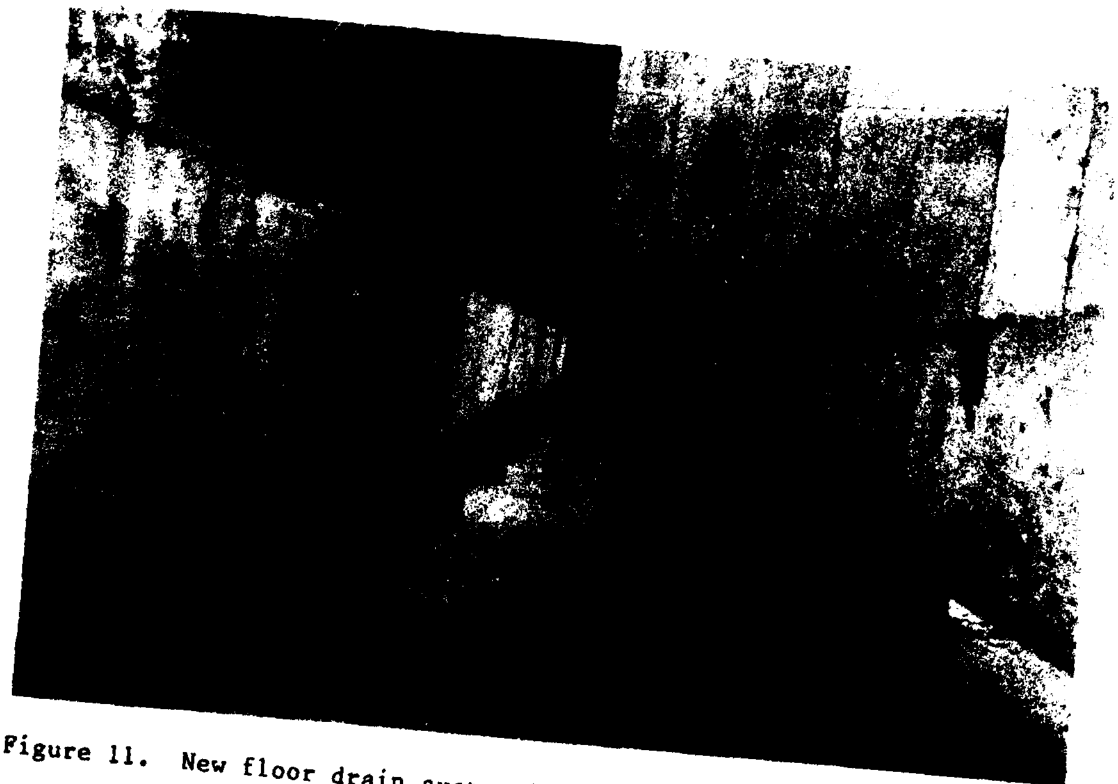


Figure 11. New floor drain system in place (column support and precast H-section concrete beams).

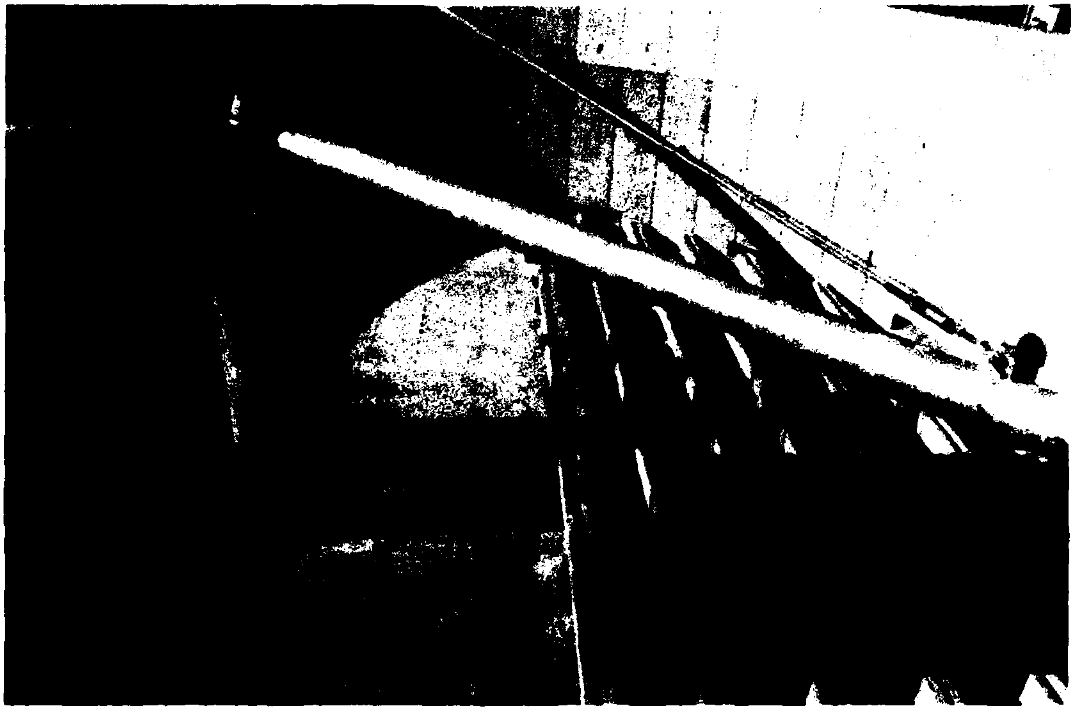


Figure 12. Renovated rotary distributor and part of the underdrain system.

Figure 13. Placing plastic media into filter.

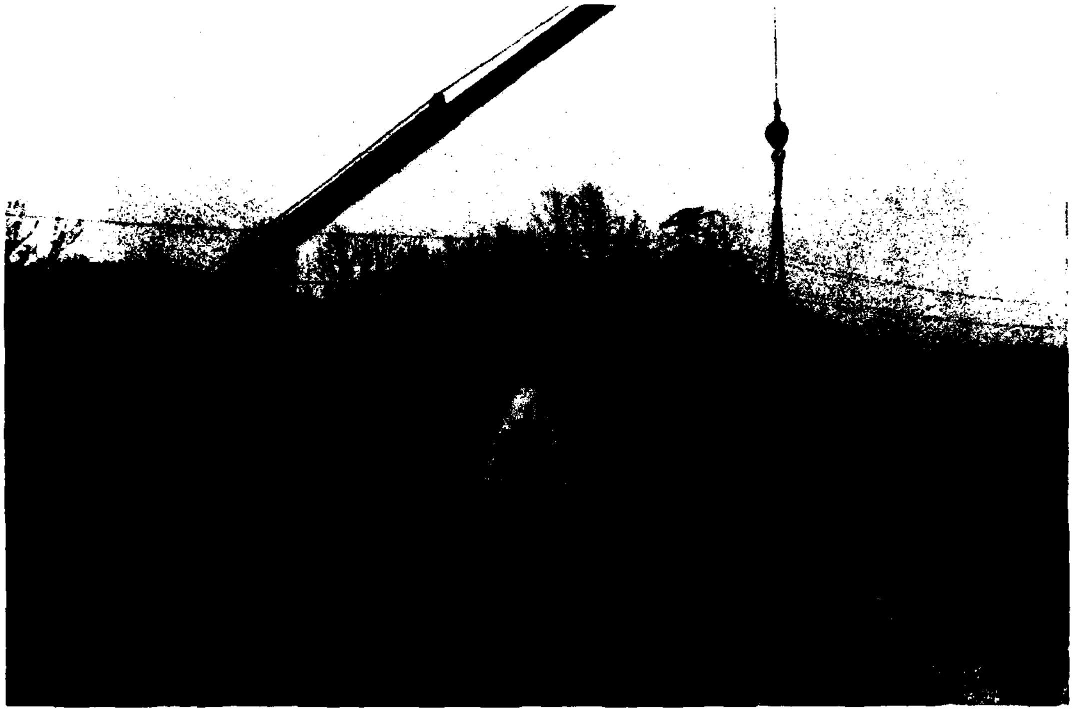


Figure 14. Erecting the plastic dome.

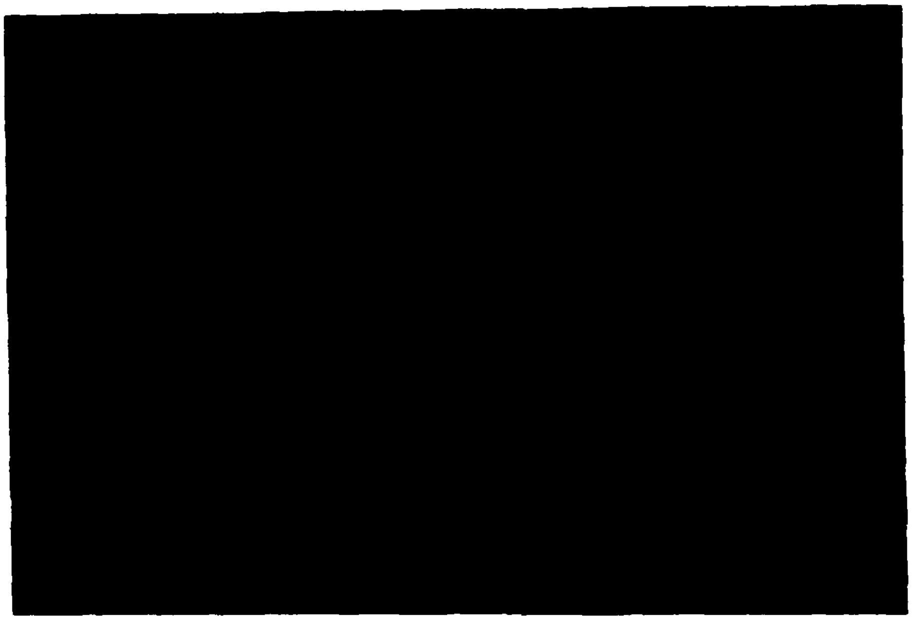


Figure 15. Finished filter.

Figure 16. Two renovated filters with the pump house between them.

The average influent BOD_5 concentration at the plant is 156 mg/L. The filters are designed to remove 50 percent of the incoming BOD_5, or the equivalent of 82 lb BOD_5/1000 cu ft per day. This is well within the range desired for plastic media used as roughing filters. The trickling-filter effluent will go to a storage tank and then to the wet well from which a recirculated flow can be applied. The recirculation ratio will be between 1.5 to 1.7, operated within a 2-ft rise-and-fall effluent level in the storage tank. The minimum hydraulic loading to each of the filters will be 1.0 gpm/sq ft, although the manufacturer recommends only 0.7 gpm/sq ft as the minimum rate needed to keep the filter wet.

Each filter is covered by a plastic dome, and an exhaust system takes gas to a scrubber for odor removal. This will avoid complaints of odors and filter flies from nearby residents. The minimum ventilation recommended is 1 cfm/lb BOD_5 removed per day, and the ventilation rate to be provided is 2.3 cfm/lb BOD_5 removed per day. Two unique processes will be used in this plant. One is lightening aeration tank design with hydraulic control of return sludge, eliminating return sludge pumping, and monitoring requirements. The other is the use of ultraviolet light for effluent disinfection.

Following are the costs for the trickling-filter renovation work, including the construction of a new trickling-filter pumping station:

Trickling filters, 2 (40-ft diameter)

Excavation	\$35,000
Concrete	
Foundations rebuilt	15,000
Walls (9-in. concrete) and miscellaneous	74,000

Piping equipment, etc.	
1. Media	60,000
2. Domes	40,000
3. Distributor revisions	10,000
Trickling-filter pump station	
Excavation	16,000
Concrete	45,000
Architectural	9,000
Pipes, valves, and equipment	59,000

RCA Mountaintop Trickling-Filtering Plant

The RCA Mountaintop Wastewater Treatment Plant originally accepted only sanitary waste, but has been modified and expanded. In 1967, the plant was enlarged by building a 52-ft-diameter rock filter. After treatment with the original small rock filter, the sanitary waste was combined with the industrial waste for treatment in the 52-ft rock filter. When the rock filter became overloaded, performance was unsatisfactory, and filamentous growth occurred. In 1975, the rock filter was converted to a plastic-media filter. The sanitary waste influent line was also disconnected, and the waste now goes to a regional sewer system.

The current influent flow is about 400 gpm, or 0.58 mgd, if the plant is in full production. The following treatment processes are used:

1. A two-step liming process raises the pH first to about 6 to 7, and then to 10. The industrial waste is primarily deionized water and acetic acid, with some zinc, copper, silver, and fluorine. The purpose of raising the pH is to decrease the solubility of the heavy metals.

2. A holding tank of about 0.25 million gal capacity provides equalization to minimize the fluctuating influent flow.

3. A primary clarifier provides flocculation and precipitation with a polymer addition to remove heavy metals and fluorine.

4. A 52-ft-diameter trickling filter is provided with a filter bed depth of 5 ft, 11 1/2 in. to 6 ft, 2 1/2 in. of randomly filled plastic media. The initially filled filter bed has some settlement (it is not known if this is normal or due to some breakage of the plastic rings) and requires some refill to provide the specified depth. The recirculation rate varies so that the hydraulic rate applied to the trickling filter is fixed at 1000 gpm. For renovation, the filter underdrain system was rebuilt; the original rotating arm and center column are retained, but the center bearing assembly is rebuilt every 3 to 4 years.

5. A secondary clarifier provides acid neutralization to a pH of 6.

6. An aerated lagoon with three units of surface aerators of 7-1/2 hp each provides about 16 hours of detention time to meet the minimum requirement for dissolved oxygen of 6 mg/L during the summer. Only one of the three aerators is required during the winter.

7. Discharge is to a wetland, no chlorination is required.

The NPDES permits for the plant are:

BOD_5	30 mg/L maximum
Suspended solids	15 mg/L average
	30 mg/L maximum
Ammonia nitrogen	12 mg/L (summer)
	15 mg/L (winter)
Dissolved oxygen	6 mg/L minimum
pH	6 to 7.5

The industrial waste coming into the treatment plant has a BOD_5 of 466 mg/L. The effluent BOD_5 from the aerated lagoon varies from 6.2 to 15.3 mg/L, and meets the NPDES permit requirement all the time.

The treatment plant has one full-time operator. No night or weekend shift is required. The operator is responsible for both operations and maintenance and chemical analyses. Solids buildup at the bottom of the plastic media often occurs, which causes a plugging problem. To keep the trickling filter functioning properly, every week the operator must apply compressed air and water to backwash the solids. A buildup of inorganic chemical on the filtering media results from chemical precipitation carried over from the chemical flocculation and precipitation treatment step. The inorganic precipitates do not come off the media as easily as a biological slime layer does. The settlement of the plastic media during the first year of operation could be either a natural phenomenon or a condition of the filter bottom which has not been investigated because access to it is difficult. If media breakage did occur at the bottom, the reduced void volume could be part of the reason for the solids buildup.

There is no dome cover for the trickling filter because there is no odor or filter fly problem. The incoming plant influent has an average temperature of 73°F so freezing is never a problem.

The total cost of plant renovation in 1975 was $456,000. The renovation included a new underdrain system for the trickling filter, replacing the rocks with plastic rings dumped at random, and some changes of the primary clarifier pumping facility.

6 DATA ANALYSIS--DESIGN, OPERATION, AND COST

This chapter provides an analysis of the data collected from literature review, manufacturers, site visits, and design engineers' information in terms of the design, operation, and costs associated with plastic-media trickling filters. Examples are furnished showing the procedure and the input data required for design and cost estimation.

Design

Sizing of Filter and Volume of Media

The Eckenfelder equation is the most commonly used design equation and has been adopted exclusively by all media manufacturers and design engineers.

By assuming m = 1.0 and n = 0.5, the Eckenfelder equation takes the following form:

$$\frac{L_e}{L_o} = \exp\ [-KD/q^{0.5}] \qquad \text{[Eq 16]}$$

where:

L_e = is filtered effluent
L_o = influent BOD_5 concentrations
D = media depth in feet
q = the hydraulic rate of application without effluent recycling expressed either in gpm/sq ft or mgad.

The K value, sometimes called a treatability factor, varies from 0.01 to 0.08 (0.06 to 0.08 for typical domestic wastewater) when q is expressed in gpm/sq ft, or from 0.2 to 0.87 when q is expressed in mgad.

When filtered effluent is recycled with a recycle ratio of R, where $R = Q_r/Q$, the Eckenfelder equation takes the following form:

$$\frac{L_e}{L_a} = \exp\ [-KD/q^{0.5}] \qquad \text{[Eq 17]}$$

where L_a = BOD_5, concentration of the influent flow diluted with the recycled effluent, and

$$L_a = \frac{L_o + RL_e}{1} + R \qquad \text{[Eq 18]}$$

Combining Eqs 15 and 16 gives the following:

$$\frac{L_e}{L_o} = [1+R\ (L_e/L_o)] \cdot [\exp(-KD/q^{0.5}]/(1+R)] \qquad \text{[Eq 19]}$$

Equations 14 and 15 are the working equations used for the following design problem. The input data for the design is taken from a design example in EM 1110-2-501.[21] The Army design results and the design results using Eckenfelder's equation are compared.

Input Data.

a. Wastewater flow

(1) Average daily flow, mgd

(2) Peak hourly flow, mgd

b. Influent BOD_5, mg/L

c. Desired effluent BOD_5, mg/L

d. Temperature, ^oC

e. Recirculation ratio

Design Parameters.

a. Reaction rate constant, k (0.0015-0.003) (from laboratory).

b. Specific surface area of the media (A_p), sq ft/cu ft (from manufacturer - [9 to 35]).

c. Media factor - n (from laboratory).

d. Hydraulic loading, gpm/sq ft = Q_o (from laboratory).

e. Sludge production factor (PF) = (0.42-0.65) lb solids/lb BOD_5.

Design Procedures.

a. Calculate the desired depth of the filter.

$$D = \frac{(Q_o n) \ \text{In} \ \dfrac{S + S(R)}{S_o + S(R)}}{KA_p} \qquad \text{[Eq 20]}$$

where:

D = depth of filter, ft

Q_o = hydraulic loading, gpm/sq ft

n = media factor

S = desired effluent BOD_5, mg/L

[21] Design of Wastewater Treatment Facilities Major Systems.

R = recirculation ratio = Q_r/Q

S_o = influent BOD_5, mg/L

K = reaction rate constant

A_p = specific surface area of the media, sq ft/cu ft

Height must be checked against $D < 30$ ft. If $D > 30$ ft, select a lower hydraulic loading (Q_o) and recalculate D.

b. Calculate the surface area of the filter.

$$SA = \frac{Q_{avg}}{Q_o(1440)} \qquad \text{[Eq 21]}$$

where:

SA = surface area, sq ft

Q_{avg} = average daily flow, mgd

Q_o = hydraulic loading, gpm/sq ft

1440 = minutes per day

c. Calculate the filter media volume

$$V = SA(D) \qquad \text{[Eq 22]}$$

where:

V = volume of media, cu ft

SA = surface area, sq ft

D = filter depth, ft

d. Calculate sludge production.

$$SP = Q_{avg}(S_o)PF(8.34) \qquad \text{[Eq 23]}$$

where:

SP = sludge produced, lb/day

Q_{avg} = average daily flow, mgd

S_o = influent BOD_5, mg/L

PF = sludge production factor, lb solids/lb BOD_5

Output Data.

a. Depth of filter, ft

b. Surface area of filter, sq ft

c. Volume of filter, cu ft

d. Hydraulic loading, gpm/sq ft

e. Recirculation ratio

f. Sludge production, lb/day.

Example Calculations.

a. Calculate desired depth of the filter.

$$D = -Q_o^n \frac{\ln\left[\frac{s + S(R)}{s_o + S(R)}\right]}{KA_p} \qquad \text{[Eq 24]}$$

where:

D = depth of filter, ft

Q_o = hydraulic loading to filter, 1.0 gpm/sq ft

n = 0.5

S = 15 mg/L

S_o = 200 mg/L

R = recirculation ratio, 100 percent, 1.0

K = reaction rate, 0.0022 ft/min

A_p = specific surface area, 30 sq ft/cu ft

$$D = -\frac{(1.0)^{0.5} \ln\left[\frac{15 + 15(1.0)}{200 + 15(1.0)}\right]}{0.0022\ (30)}$$

D = 29.8 ft, say 30 ft.

b. Calculate surface area of filter.

$$SA = \frac{Q_{avg}}{Q_o(1440)} \qquad \text{[Eq 25]}$$

where:

SA = surface area, sq ft

Q_{avg} = average flow, 1.0 mgd

Q_o = hydraulic loading, 1.0 gpm/sq ft

$$SA = \frac{1.0 \text{ mgd}}{(1.0 \text{ gpm/ft}^2)(1440 \text{ min/day})}$$

$$SA = 694 \text{ sq ft}$$

c. Calculate volume.

$$V = SA(D) \qquad \text{[Eq 26]}$$

where:

V = volume of filter, cu ft

SA = surface area, 694 sq ft

D = depth, 30 ft

$$V = 694\ (30)$$

$$V = 20{,}820 \text{ cu ft}$$

The sludge production calculation for this example is not shown here. The sludge production factor in lb solids/lb BOD_5, PF, varies from plant to plant, so it is not meaningful to provide comparisons. Theoretically, the same type of trickling filter, designed and operated with identical conditions and with the same wastewater produces the same amount of sludge.

If no recirculation of filter effluent is applied, then the Army equation is simplified as follows:

$$D = \frac{Q_o n \ln\left(\frac{S}{S_o}\right)}{KA_p} \qquad \text{[Eq 27]}$$

$$= - \frac{(1.0)^{0.5} \ln\left(\frac{15}{200}\right)}{0.0022\ (30)}$$

$$= 39.25 \text{ ft.}$$

Using the Eckenfelder equation with the same input data and K rate of 0.06, and with recirculation,

$$\frac{L_e}{L_o} = [1+R(L_e/L_o)]\ [\exp(-KD/q^{0.5})]/(1+R) \qquad \text{[Eq 28]}$$

$$\frac{15}{200} = [1+1.0(15/200)]\ [\exp(-0.06\ D/1.0^{0.5})]/(1+1.0)$$

$$D = 32.8 \text{ ft.}$$

Without recirculation,

$$L_e/L_o = \exp[-KD/q^{0.5}] \qquad \text{[Eq 29]}$$

$$15/200 = \exp[-0.06\ D/1.0^{0.5}]$$

$$D = 43.2 \text{ ft.}$$

Regardless of which design equation is used and whether recirculation is applied, the filter surface area remains

$$SA = \frac{1.0 \text{ mgd}}{(1.0 \text{ gpm/sq ft})(1440 \text{ min/day})} \qquad \text{[Eq 30]}$$

$$= 694 \text{ sq ft}$$

The filter media volume for each case is simply V = SA(D). Table 32 lists the results for comparison.

The results in Table 32 indicate that greater media depth and volume are required when Eckenfelder equations are used. Different results are expected when different design equations are used. Everything else being equal, the K-values chosen for the different design equations significantly affect the outcome. For better design, the K-value, as well as other exponent values (i.e., m and n) should be determined with a pilot-plant study.

The example above shows media depth ranging from 29.80 to 43.2 ft. Deep filters are more cost-effective, since the volume of media required decreases as the filter depth increases. To take advantage of this unique feature, tall, lightweight towers of trickling filters housing plastic media are built. By adding another 6 ft of media support system and freeboard to the media depth, the filter tower in the example given here would be from 36 to 40 ft. However, lightweight design and construction of tall towers to such heights is questionable. All known existing tall-tower trickling filters have a media depth ranging from 16 to 28 ft, with a significant number of them between 20 to 22 ft. Therefore, the design problem is more realistically approached by using two filters of identical size, both with the same diameter as the single filter, and each handling a 0.5-mgd rate of flow. Table 33 lists the results for comparison.

Table 32

Filter Media Volume Comparison

One Filter With 1.0 mgd Design Flow

	Media Depth ft	Filter Surface Area ft^2	Media Volume ft^3
Army Design Equation:			
K-rate = 0.0022 ft/min			
Without recirculation	39.25	694	27,240
With recirculation R = 1.0	29.80	694	20,700
Eckenfelder Equation:			
K-rate = 0.06			
Without recirculation	43.2	694	30,000
With recircuation R = 1.0	32.8	694	22,760

Table 33

Media Depth Comparison

Two filters, each with 0.5 mgd* design flow

	Media Depth Each Filter ft	Filter Surface Area Each Filter ft	Media Volume Each Filter ft
Army Design Equation:			
K-rate = 0.0022 ft/min			
Without recirculation	28	694	19,430
With recirculation R = 1.0	22	694	15,300
Eckenfelder Equation:			
K-rate = 0.06			
Without recirculation	30	694	20,800
With recirculation R = 1.0	24	694	16,660

*0.5 gpm/sq ft hydraulic application rate.

This solution requires a 39 to 48 percent increase of media volume over the previous solution. However, this two-filter system provides a 50 percent backup capacity (a feature often required by all regulating agencies), while the one-filter system has no backup.

It is important to note that a design with effluent recirculation results in shallower or lesser media depth and volume requirements. Recirculation capability has to be provided even for tall filters with plastic media because a minimum wetting rate of 0.2 gpm/sq ft is required. Therefore, one should take advantage of the savings in capital costs by incorporating recirculations in the design. However, the added cost of a large recirculating pump facility and the power requirement for recirculation in high tower operation should be considered since it may offset the savings in capital cost.

The K-value for the design should be adjusted for different temperatures, using $K_{T2} = K_{T1} \times 1.035^{(T2-T1)}$, where T1 is the temperature at which a K-value is given (by the manufacturer or pilot testing), and T2 is the design wastewater temperature.

Air Requirements

Shallow filters with a bed depth of less than 8 ft usually depend on natural convection air currents for air supply. For taller filter towers, particularly those with a large diameter, forced aeration is usually provided to ensure an adequate supply of oxygen to the biofilm deep within the filter.

For naturally ventilated towers, some manufacturers recommend air openings of 2 sq ft/1000 cu ft of media volume. The openings, preferably distributed uniformly around the base of the tower, should be a minimum of 12 to 18 in. high. Some of these openings should be closed off in cold weather to minimize heat loss of the wastewater as it passes through the filter bed.

When forced aeration is applied, the air requirement can be calculated based on the amount of BOD_5 to be removed by the trickling filter, and knowing the amount of BOD_5 removal requirement in lb/day basis; the following assumptions are used:

1 lb O_2 required/lb BOD_5 removed

Concentration of oxygen in air = 20 percent

Weight of air = 0.075 lb/cu ft

O_2 utilization = 5 percent (this is a conservative assumption, ensuring plenty of air going through the filter, even deep within the filter bed).

$$\text{Air requirement} = (1 \text{ lb } O_2/\text{lb } BOD_5 \text{ removed}) \times \frac{1}{.20} \times \frac{1 \text{ cu ft}}{.075 \text{ lb}} \times \frac{1}{.05}$$

$$= 1333 \text{ cu ft air/lb } BOD_5 \text{ removed per day,}$$

or about 1.0 cfm air/lb BOD_5 removed per day.

For example, at the Suffern Municipal Wastewater Treatment Plant the design ventilation rate is 1.0 cfm air/lb BOD_5 removed per day, but 2.3 cfm air/lb BOD_5 removed per day capacity is actually provided.

For the design example of 1 mgd flow rate and BOD_5 reduction from 200 to 15 mg/L, the required capacity is:

1.0 mgd x 8.34 (conversion factor for mg/L to lb/mg) x (200 - 15) mg/L x 1 cfm/lb = 1543 cfm

It is very important to note that the air requirement estimation using this procedure provides the maximum possible air needed. While the blowers are provided, they may not be used in daily operation since natural ventilation normally provides enough air to the filter. Some deep filters with 30 ft of media are not equipped with blowers, and rely entirely on natural ventilation and on increasing the recirculation of occasional high BOD_5 loads and reducing the effluent dissolved oxygen to a low level.

Power Requirements

Trickling-filter tower operations need power for pumping wastewater to the filter-top rotary distributor, with or without recirculation, and for forced ventilation, if needed.

Wastewater pumping, without recirculation:

$$\text{hp} = \frac{\text{Flow mgd x 694 gpm/mgd x (media depth + 6 ft)}}{\text{3960 ft-gallon/min-hp x 0.67 pump and motor efficiency}}$$

where 6 ft accounts for the height of the media support system and distributor (about 5 ft) and head losses through the pumping and pipe system. For the design example of two filters with a total flow of 1 mgd, and a 30-ft media depth each:

$$\text{hp} = \frac{0.5 \times 694 \times (30+6)}{3960 \times 0.67}$$

$$= 4.7 \text{ per two filters}$$

Wastewater pumping, with recirculation:

$$\text{hp} = \frac{(Q_o + Q_r)}{Q_o} \times \text{hp requirement for flow without recirculation}$$

$$= 2 \times 4.7$$

$$= 9.4 \text{ per two filters}$$

Air supply:

Two blowers, each providing up to 1000 cfm of air flow (2 x 1000 > 1543 cfm required) at low pressure would require about 14 hp each.

Filter Bottom

Typically, in rock filters, the filter underdrain blocks accept effluents which drain to the channel or channels leaving the filter. However, for plastic media modules, site-specific supporting beams are used which can sit either on the sloping floor or on concrete blocks (columns); the top of these beams is level, since the plastic media modules must be laid horizontally and on the same level. Both precast concrete beams and cast-in-place beams can be used as shown in Figures 17 and 18. Figure 19 shows that the bottom layer of media is placed over the support in a staggered parallel pattern. All successive layers are placed in a herringbone pattern to assure optimum structural strength and distribution of wastewater. The wastewater treatment plants at both Fort Lewis, WA, and Suffern, NY, use this beam support system; pressure-treated wood beams can be used in place of concrete beams.

For smaller-diameter towers, a strip grating support system placed over a flat-top concrete beam system, as shown in Figure 20, can be constructed much more simply. Seneca Army Depot Plant No. 4 uses this grating-on-beams support system, which is most suitable for supporting small plastic-media units.

Figures 21 and 22 show details of filter bottom designs for center column, round tower, and locations of air openings.

Filter-Tower Wall Construction

Lightweight construction is allowed for filter-tower walls when plastic media are used. Figures 23 and 24 show two types of such construction: one was a polyester fiberlass and lightweight steel containment structure, and the other a precast double-tee concrete containment structure. The filter towers at Fort Lewis, WA, with 21 1/2 ft of media are constructed of metal panels placed on metal framing (see Figure 25).

Evaluation of the Coefficient and Exponent Values for the Design Equations

The Eckenfelder design equation, $L_e/L_o = \exp[-KD^m/q^n]$, contains three constant values: K, m, and n. K is a treatability coefficient or factor which is wastewater-specific. Although most manufacturers suggest a narrow range of domestic wastewater K-values, from 0.06 to 0.08 for design, most wastewater, including municipal and industrial wastes, may have a K-value significantly outside that range (i.e., 0.01 to 0.08). The pilot plant study at the Suffern Municipal Wastewater Treatment Plant indicated a K-value of 0.1. For better design of the filters, it is recommended that the K-value be determined either experimentally or by using a pilot plant study specifically for the wastewater in question. The other constant values--m and n, respectively--reflect the effect of media and how they are packed in the filter bed on the effective depth (synonymous with hydraulic detention time), and the effect on the hydraulic application rate. Although most manufacturers assign $m = 1$ and $n = 0.5$ for their plastic media products, this value is by no means correct for all design applications. Table 13 showed a wide range of n values, even among the several plastic media tested.

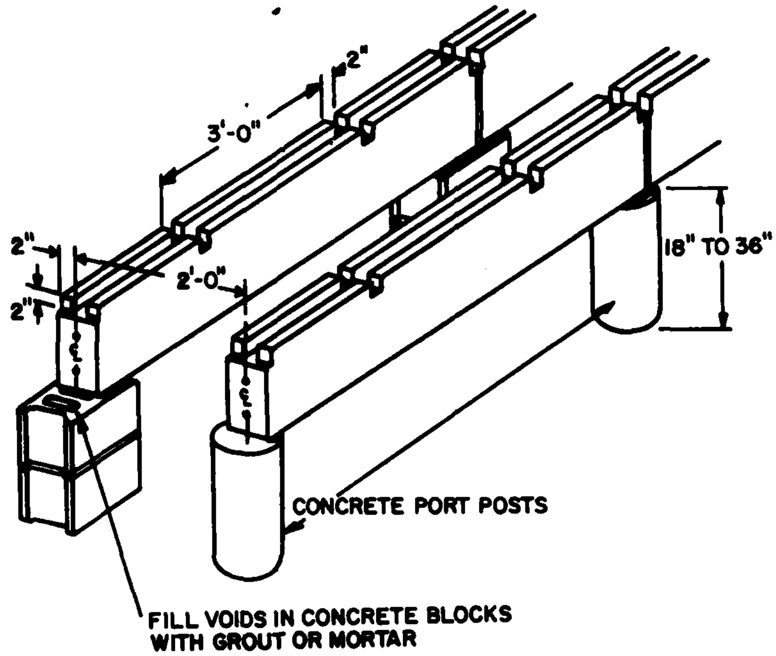


Figure 17. Precast concrete beam supports. (From Drawing 2, Information Bulletin, VC 2.1-276 [B. F. Goodrich].)

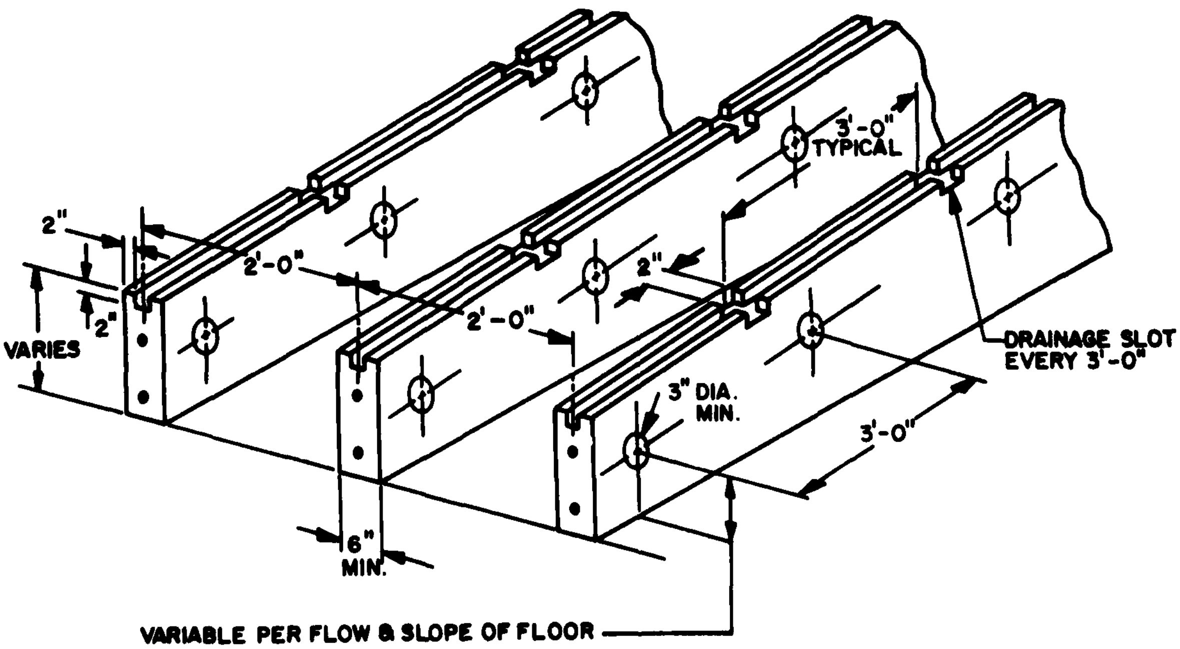


Figure 18. Cast-in-place beam construction. (From Drawing 3, Information Bulletin [B. F. Goodrich].)

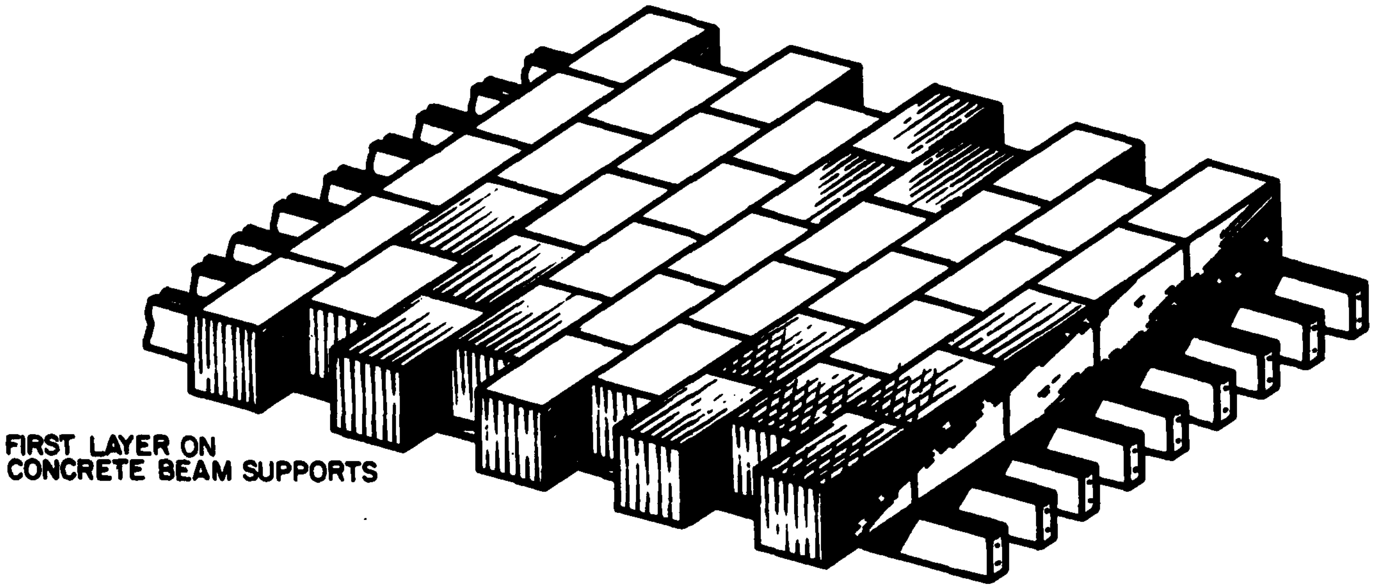


Figure 19. Precast concrete beam supports. (From Drawing 1, Information Bulletin [B. F. Goodrich].)

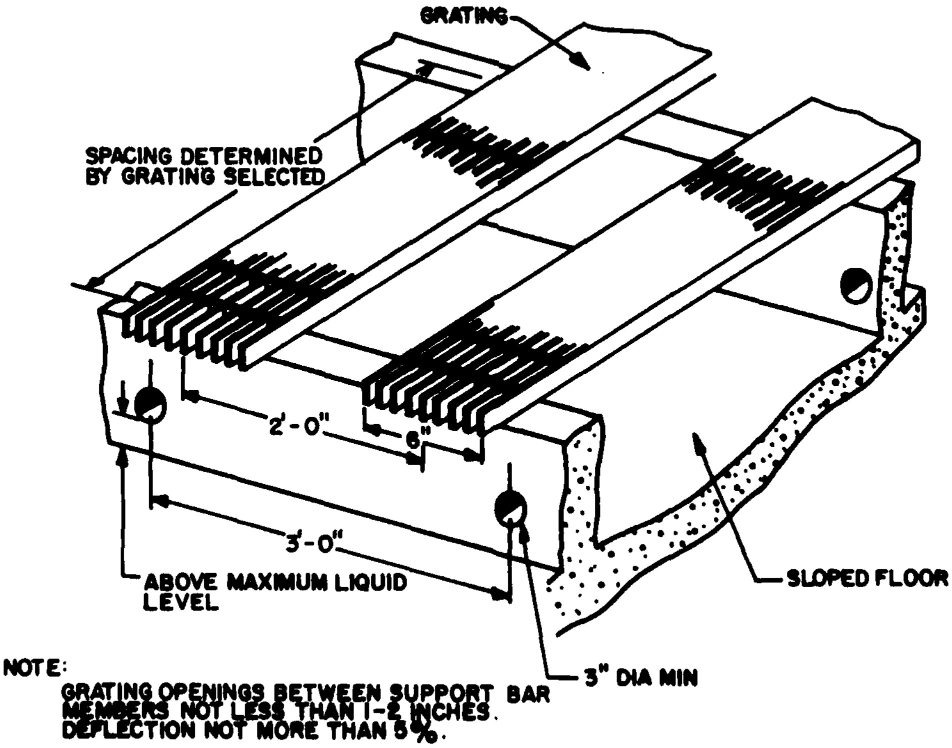
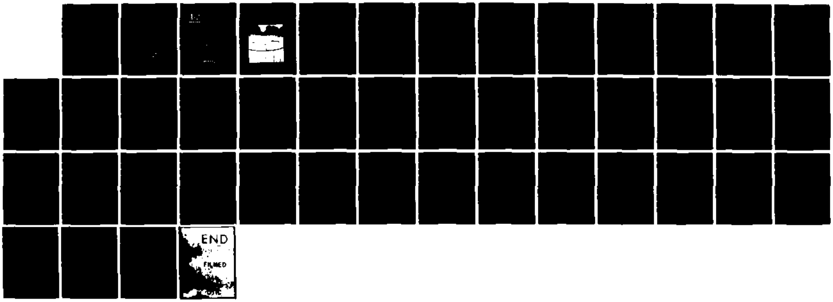
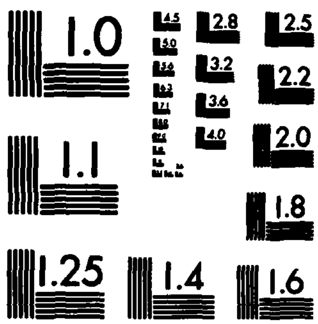


Figure 20. Staggered grating support over cast-in-place beams. (From Drawing 2, Information Bulletin [B. F. Goodrich].)

AD-A145 648 UPGRADING ARMY SEWAGE TREATMENT PLANT TRICKLING FILTERS 2/2
WITH SYNTHETIC MEDIA(U) CONSTRUCTION ENGINEERING
RESEARCH LAB (ARMY) CHAMPAIGN IL C P POON ET AL.
UNCLASSIFIED AUG 84 CERL-TR-N-182 F/G 13/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

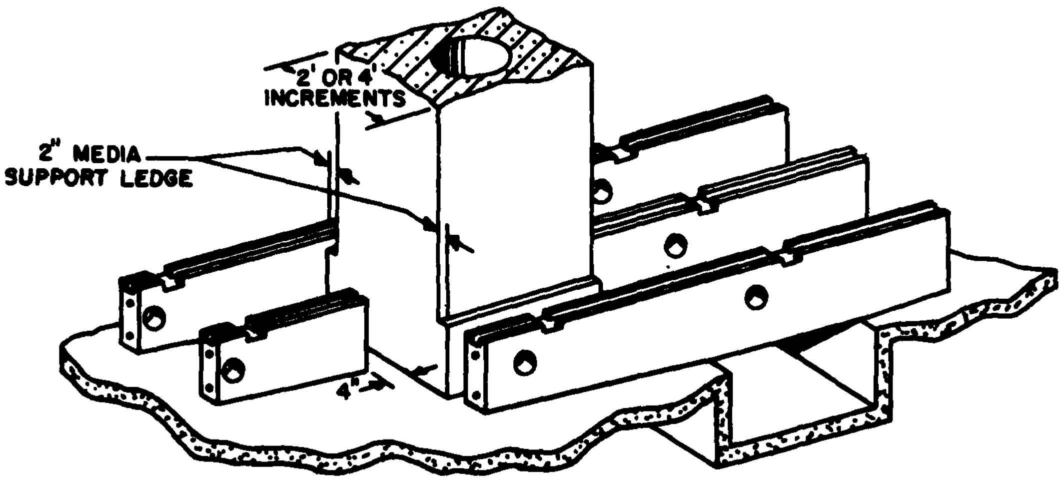


Figure 21. Preferred center column design. (From Drawing 5, Information Bulletin [B. F. Goodrich].)

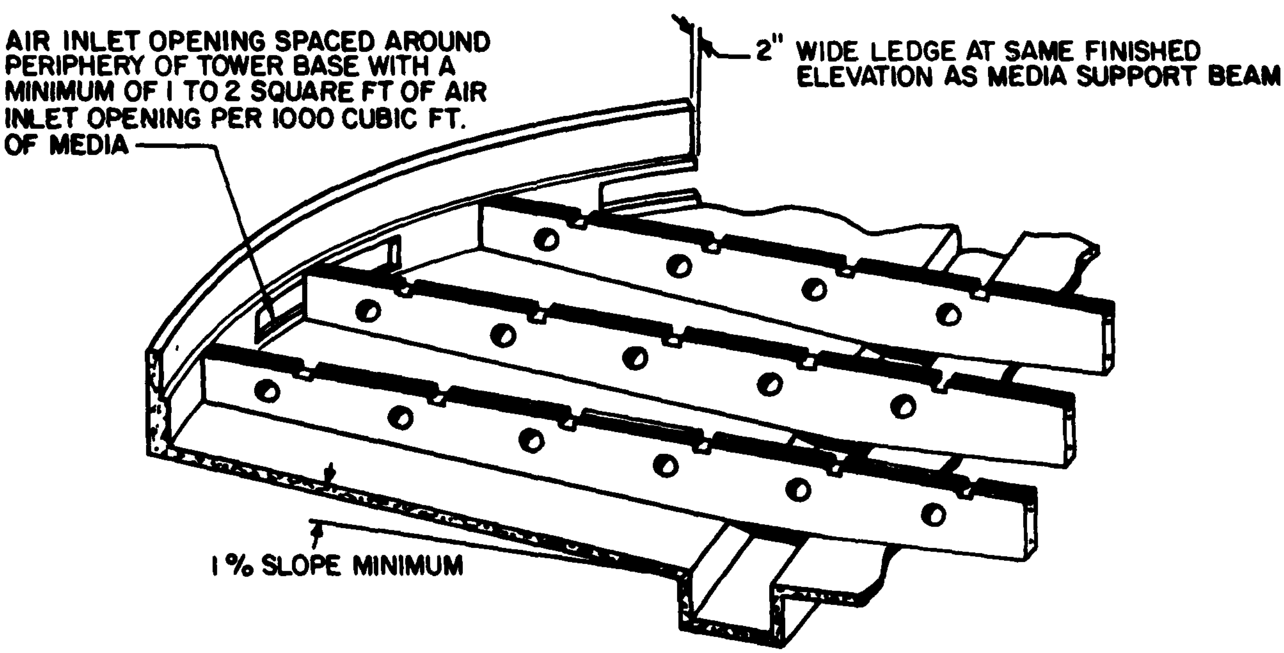


Figure 22. Round tower with underdrain and cast-in-place beams. (From Drawing 6, Information Bulletin, [B. F. Goodrich].)

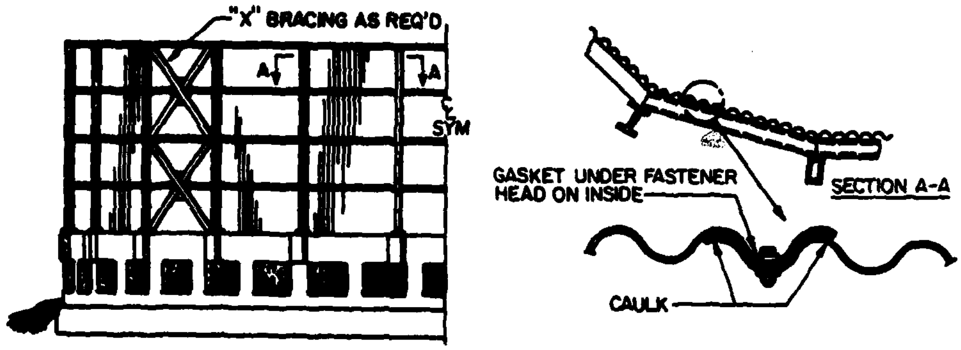


Figure 23. Polyester fiberglass and lightweight steel containment structures with details. (From Drawing 7, Information Bulletin [B. F. Goodrich].)

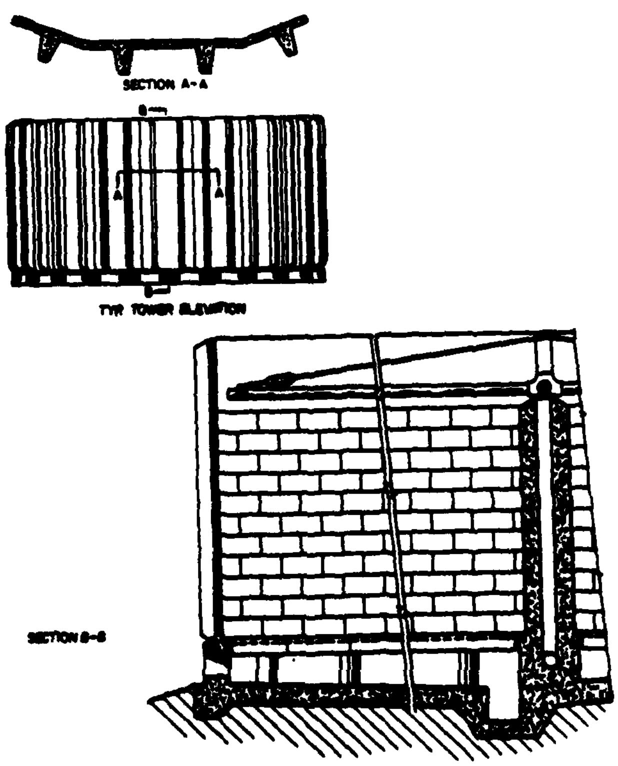


Figure 24. Precast double-tee containment structure and section. (From Drawing 8, Information Bulletin [B. F. Goodrich].)

U.S. Army Headquarters,
9th Infantry Division,
Fort Lewis, Washington--
2-81 ft. dia. x 21.5 ft. deep
single-stage high rate
Surfpac Towers treating up
to 15 MGD to 85-90% BOD_5
and TSS removal.

CH_2M·Hill Consulting Engineers
Bellvue, Washington

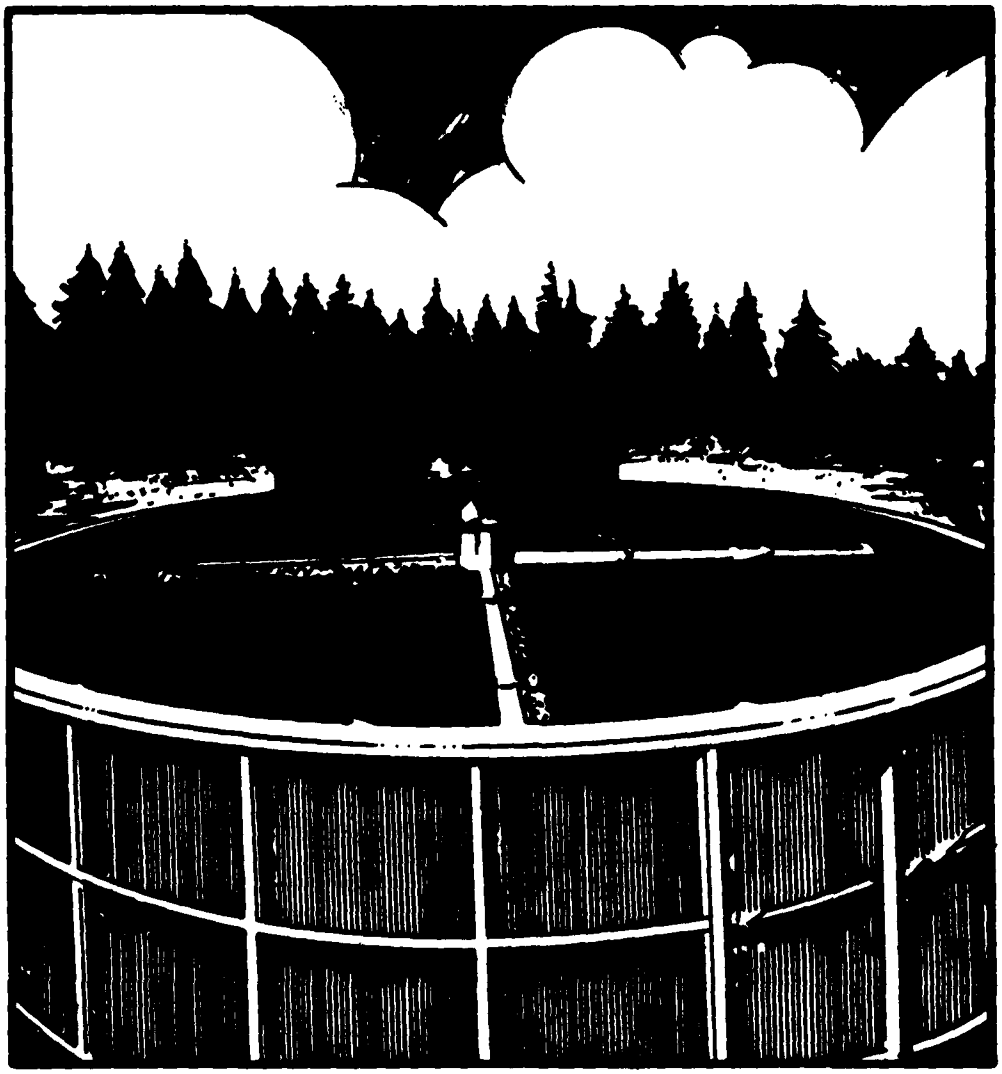


Figure 25. Filter tower at Fort Lewis, WA. (From Bulletin, SBCT-11-3K82 [American Surfpac].)

The following paragraphs describe a laboratory-scale testing filter and its use for determining the K, m, and n values. Various hydraulic application rates, q, are used in a series of experiments, and BOD_5 concentrations of the influent and effluents at different filter depths are determined.

The trickling filter model built by Balakrishnan, et al.[22] was a 20-in.-diameter, 9-ft-deep filter with an air sparger to provide a uniform air distribution from the bottom and distribution plates on top for uniform hydraulic loading. The model filter was packed to a depth of 8 ft, using a 1.5-in. polypropylene Flexiring medium. The filter medium had 96 percent free space and 40 sq ft/cu ft of specific surface. The model filter was acclimated with settled domestic sewage and operated at 14°C as a secondary treatment system without recirculation. Samples were collected at various depths in the filter for laboratory analysis, and the samples were settled for 30 minutes and filtered through a Whatman No. 42 filter paper before testing of effluent BOD_5. Figure 26 shows the experimental data obtained at three filtration rates: 0.2, 0.3 and 0.43 gpm/sq ft.

For graphing purposes, the Eckenfelder equation is rewritten in the following form:

$$\ln(100L_e/L_o) = 100 - Kq^{-n}D^m \qquad \text{[Eq 29]}$$

In Figure 26, the slope is $-Kq^{-n}$, the ordinate is $\ln(100L_e/L_o)$, and the abscissa is simply D, not D^m. Since the experimental data can be expressed as three straight lines on the semi-logarithmic plot, one can reasonably assume the values of m are equal to 1. The equation of slope is rewritten as:

$$\ln(-\text{slope}) = \ln(K) - n\ln(q) \qquad \text{[Eq 30]}$$

Accordingly, the slopes of the curves for BOD_5 remaining versus depth (Figure 26) can be plotted against their respective hydraulic rates on the logarithmic graphical sheet, and the constant n is then determined to be 0.39 (Figure 27).

Finally, Eckenfelder's Equation is reconsidered, and the constant K can be determined, as shown in Figure 27, by plotting $q^{-n}D^m$ versus 100 L_e/L_o on semi-logarithmic paper. The K-value at the wastewater temperature, 14°C, was determined to be 0.375. The K-rate at 20°C is then calculated by using the correction factor presented earlier.

$$K \text{ at } 20°C = 0.375 \times 1.035^{(14-20)}$$

$$= 0.46$$

[22] S. Balakrishnan, et al., 1969.

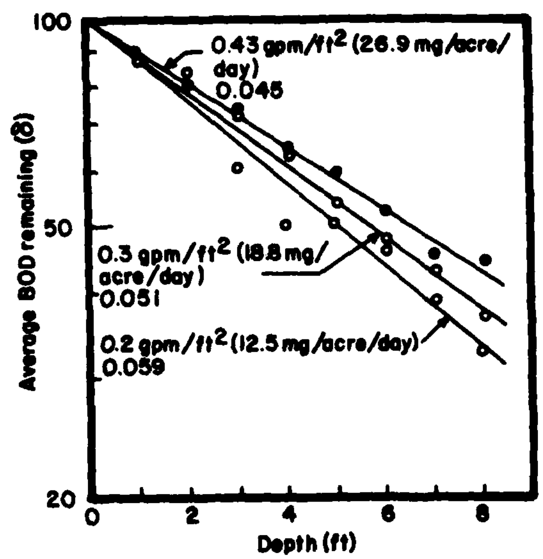


Figure 26. Relation between filter depth and percent BOD_5 remaining at various hydraulic loads. (From S. Balakrishnan, et al.)

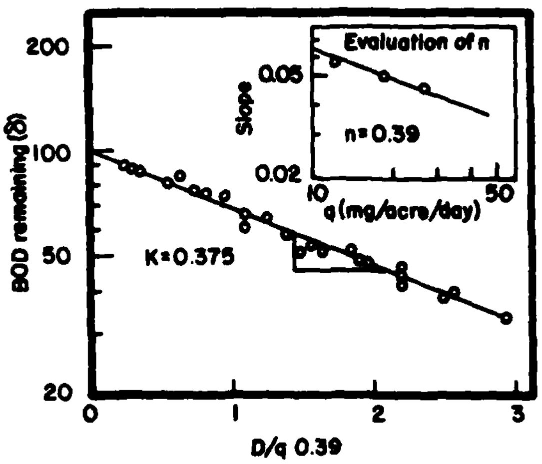


Figure 27. Diagrams for the determination of constants n and K in Eckenfelder's model. (From S. Balakrishnan, et al.)

Substituting values of m = 1, K = 0.46 and n = 0.39 in the equations, the BOD_5 removal relationship for the specific filter medium tested, the specific wastewater treated, and under the described operational conditions, is:

$$L_e/L_o = \exp\,(-0.46D/q^{0.39})$$

This approach can also be used to evaluate the K, m, and n values. It should be noted that K = 0.46 is based on q expressed in the mgad unit. If q is expressed in the gpm/sq ft unit, the equivalent K-value will be 0.09.

Nitrification

As in other types of fixed-film biological processes, such as the RBC, plastic-media trickling filters can be designed and have been successfully used in wastewater treatment plants for nitrification purposes. The nitrification design procedure is different from that of carbonaceous BOD_5 removal, as described in a Norton Industrial Ceramics Division publication:

> However, some wastewater treatment facilities have experienced simultaneous carbonaceous oxidation and nitrification in one process system. The combined carbonaceous oxidation-nitrification processes generally have too high a BOD_5 to total Kjeldahl Nitrogen (TKN) ratio to achieve high levels of nitrification. The majority of the oxygen requirement for these combined processes is for the carbonaceous oxidation.
>
> In separate stage nitrification, there is a lower BOD_5 load relative to the influent ammonia load. As a result, a higher proportion of nitrifiers is obtained, resulting in higher rates of nitrification. The bulk of the oxygen requirements in the nitrification stage is for the ammonia oxidation. To obtain separate stage nitrification, pretreatment is required to lower the organic load or BOD_5/TKN ratio in the influent to the nitrification stage.
>
> The development and maintenance of nitrifying organisms in a packed biological reactor is dependent on a variety of factors including organic loading, temperature, pH, dissolved oxygen and the presence of toxicants. The rate of nitrification is proportional to the surface area exposed to the liquid being nitrified. In other words, when all other factors are held constant, the allowable loading rates are related to the wetted media surface area rather than to the media volume.
>
> The following is a step by step outline to calculate the nitrification tower size and hydraulic loading. It is assumed in Steps 1 through 8 that the organic loading (BOD_5) is within an acceptable range (less than 30 mg/L).

Step 1. Calculate the pounds of ammonia nitrogen to be oxidized.

Step 2. From Figure 28, determine the surface area in the packed biological reactor required to oxidize one pound of ammonia nitrogen to nitrate nitrogen to attain the desired effluent at your specific temperature.

Step 3. Multiply the surface area number determined in Step 2 by the total pounds of ammonia nitrogen to be oxidized, which was determined in Step 1.

Step 4. Calculate the total packed biological reactor media volume by dividing the total surface area required (Step 3) by the specific surface area of the media.

Step 5. Select an irrigation rate from the range between 0.5 gpm/ft^2 to 1.5 gpm/ft^2 The irrigation rate should include recycle around the PBR. The recommended recycle ratio is normally 1:1.

Step 6. Calculate the cross-sectional area of the nitrification PBR by dividing the raw flow (GPM) plus the recycle flow (GPM) by the irrigation rate (GPM/ft^2) selected in Step 5.

Step 7. Calculate the diameter of the PBR from the cross-sectional area figure determined in Step 6.

Step 8. Calculate the media depth required by dividing the media volume determined in Step 4 by the cross-sectional area figure calculated in Step 6.

If the calculated media depth figure is too high or too low or the calculated diameter is too large or too small, change the irrigation rate selected in Step 5.

Step 9. The purpose of this step is to determine that the organic loading (BOD_5) is not dominating the nitrification efficiency required.

Calculate the total pounds of BOD_5 applied per 1000 cu ft of specific surface area of the media. From Figure 29, determine the nitrification efficiency for the BOD_5 loading calculated and check to see if this efficiency matches the required efficiency calculated in Step 1.

If the efficiencies do not agree, the total surface area per pound of ammonia oxidized should be increased.

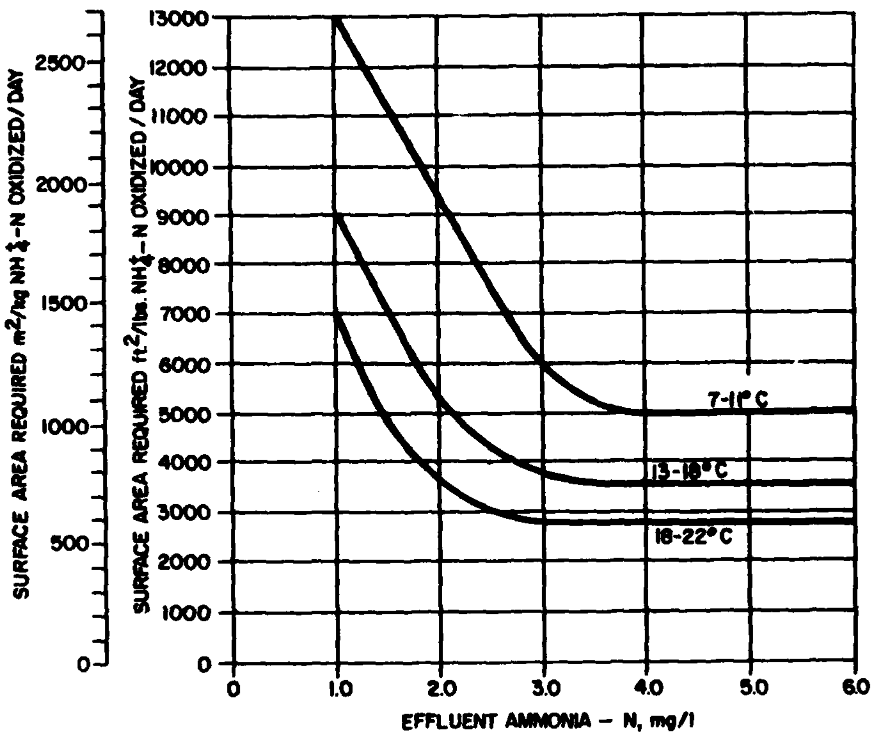


Figure 28. Surface area requirements for nitrification.

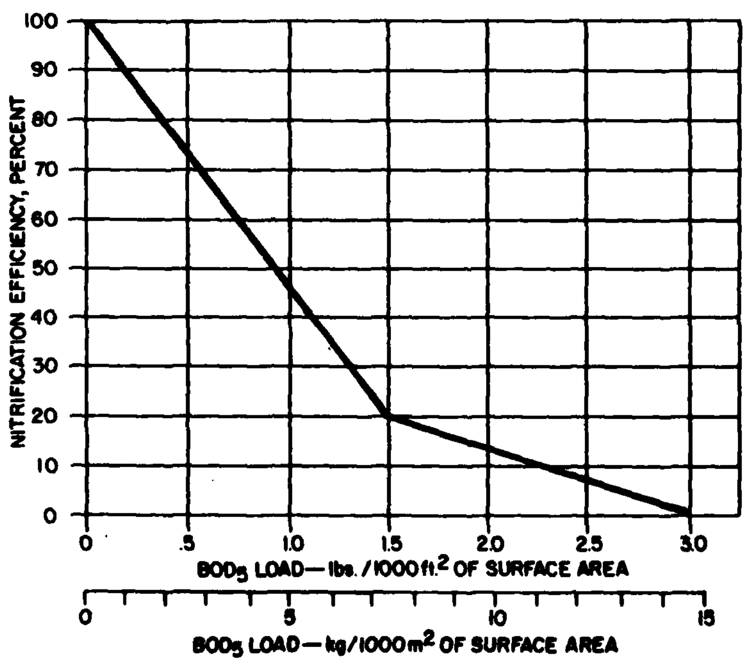


Figure 29. Effect of organic loading on nitrification efficiency.

Repeat Steps 2 through 9 with the new surface area figure until the efficiencies agree.

The prevalent design approach for nitrification using trickling filters as recommended by media manufacturers and most design engineers is to determine the media surface area requirement according to the specified effluent NH_3-N concentration with temperature adjustment. The determination of the surface area requirement relies on the data presented in the EPA's Process Design Manual.[23]

As an example of nitrification design, the design problem presented for carbonaceous BOD_5 removal (p 88) is continued.

Design flow = 1.0 mgd

Secondary effluent BOD_5 = 15 mg/L, from filters for carbonaceous BOD_5 removal or first-stage filters as previousy designed (20°C)

Secondary effluent NH_3-N = 20 mg/L

Secondary effluent TKN = 23 mg/L

Alkalinity = 165 mg/L (expressed as $CaCO_3$)

NPDES permit requires NH_3-N = 3 mg/L after nitrification in the winter with wastewater average temperatures at 15°C

Recirculation ratio = 1.0.

Example calculations:

NH_3-N concentration in the combined influent and recirculated

$$\text{flow} = \underline{20 \text{ mg/L} + 1.0 \times 3 \text{ mg/L}}$$

$$= 11.5 \text{ mg/L}$$

$$NH_3 \text{ to be oxidized} = (11.5-3) \text{ mg/L} \times 8.34 \frac{\text{lb/million gallons}}{\text{mg/L}} \times (1+1) \text{ mgd}$$

$$= 141.8 \text{ lb/day.}$$

From Figure 28, for a final effluent of 3 mg/L of NH_3-N, the surface area per pound of NH_3-N oxidized at 15°C is 3700 sq ft-day/lb.

The surface area required, SA = 3700 sq ft-day/lb x 141.8 lb/day

= 524,660 sq ft.

Use a plastic media with a specific surface area, A_p = 30 sq ft/cu ft.

[23] Process Design Manual for Nitrogen Control.

Media volume required = 524,660 sq ft/(30 sq ft/cu ft)

= 17,490 cu ft

Use a hydraulic application rate or loading of 1.2 gpm/sq ft, including 1:1 recycle. The filter surface area is then:

$$A = (1+1)\text{ mgd} \times (10^6\text{gal/m.g})/(1.2\text{ gpm/sq ft} \times 1440\text{ min/day})$$

$$= 1157\text{ sq ft.}$$

$$\text{Media depth} = \frac{17{,}490\text{ cu ft}}{1157\text{ sq ft}} = 15.1\text{ ft.}$$

$$\text{Filter diameter} = 2\sqrt{\frac{A}{\pi}} = 2\sqrt{\frac{1157}{3.14}} = 38.4\text{ ft.}$$

Check the BOD_5 loading to the nitrification filter.

First, calculate the effluent BOD_5 using the Eckenfelder Equation with recirculation (Eq 15):

$$\frac{L_e}{L_o} = [1+R(L_e/L_o)][\exp(-KD/q^{0.5})]/(1+R)$$

or

$$L_e = \frac{L_o \exp[-KD/q^{0.5}]}{(1+R)-[R \exp[-KD/q^{0.5}]]}$$

The K-value used previously, 0.06, is assumed for 20°C wastewater temperature. For correction of K-value to 15°C:

$$K_{15^oC} = 0.06 \times 1.035^{(15-20)}$$

$$= 0.051$$

The BOD_5 concentration of the secondary effluent at 15 mg/L corrected to temperature 15°C should be:

$$L_e = \frac{200 \exp[-0.051\text{x}24/0.5^{0.5}]}{(1+1)-[1.0 \exp[-0.051\text{x}24/0.5^{0.5}]]}$$

$$= 19.4\text{ mg/L}$$

where 24 ft is the media depth previously calculated for the filter tower for carbonaceous BOD_5 removal (at 20°C removing BOD_5 from 200 to 15 mg/L).

Therefore, BOD_5 concentrations of the nitrification filter effluent

$$= \frac{19.4 \exp[-0.051 x 24/0.5^{0.5}]}{(1+1)-1.0 \exp[-0.051 x 15.1/1.0^{0.5}]}$$

$= 5.8$ mg/L.

BOD_5 loading to nitrification filter

$$= \frac{19.4 + (1 \times 5.8)}{1+1}$$

$= 12.6$ mg/L.

or $\quad 12.6 \text{ mg/L} \times \frac{8.34 \text{ lb/mg}}{\text{mg/L}} \times (1+1)\text{mgd}/524{,}660 \text{ sq ft}$

$= 0.40$ lb BOD_5/1000 sq ft of media surface area.

From Figure 29, the nitrifying efficiency is 77 percent at 0.40 lb BOD_5/1000 sq ft loading.

The required nitrifying efficiency according to the input data is

$100 \times \frac{(20-3) \text{ mg/L}}{20 \text{ mg/L}} = 85$ percent overall. When recycled flow is

added, the efficiency is $100 \times \frac{(11.5-3) \text{ mg/L}}{11.5 \text{ mg/L}} = 74$ percent required.

Therefore, the media surface area is satisfactory.

Check the alkalinity requirement:

$$\text{Alkalinity requirement} = (11.5 - 3.0) \text{ mg/L} \times \frac{9.5 \text{ mg/L } CaCO_3}{\text{mg/L } NH_3\text{-N nitrified}}$$

$= 81$ mg/L as $CaCO_3$.

By mass balancing, the alkalinity around the filter is

$$\frac{[\text{Alk req'd} \times 1.0 \text{ mgd} + (\text{Alk req'd} - 81 \text{ mg/L}) \times 1.0 \text{ mgd}]}{(1+1) \text{ mgd}} = 81 \text{ mg/L}$$

The alkalini' required = 121.5 mg/L in the secondary effluent.

Since 165 mg/L alkalinity is available, the requirement is satisfied.

Filter Renovation

A significant number of trickling-filter installations in the United States are the shallow rock-filter type. Many were designed and constructed years ago, and some are having operations difficulties and not meeting NPDES permit requirements because of hydraulic and/or organic overloading. While many plants are abolishing the trickling filters and replacing them with other

forms of biological processes, such as activated sludge or rotating biological contactor (RBC), others are renovating the deteriorating filters to upgrade treatment performance. The scope and method of renovation is site-specific. There are two basic types of filter renovation:

1. Replace the filter rocks with plastic media. The filter depth may or may not be increased. The filter is retained as the sole biological treatment unit of the plant.

Examples of this type of filter renovation are found at the Seneca Army Depot Wastewater Treatment Plant Number 4 and at the RCA Corporation plant in Mountaintop, PA. Both renovations required only the construction of a new support and drainage system for the plastic media and replacing the rocks with plastic media. The filter wall, center column, and rotary distributors were retained. In both cases, treatment efficiency has been successfully upgraded to meet new NPDES permit standards for secondary treatment. The renovation work for each case is considered the minimum required for upgrading except in the case of Seneca Army Depot where an aluminum filter cover is added (the cover would not affect the treatment performance).

2. Filter media are replaced with plastic media or new rock media. The depth of the filter media may or may not change. The renovated filter is then used in one of the two following schemes:

a. As a roughing filter, followed by another treatment process to complete the secondary treatment

b. As a polishing filter preceded by another treatment process, which together provide secondary or greater treatment.

Examples of this type of filter renovation are found in the wastewater treatment plant at Fort Bragg, NC, and in the Suffern Municipal Sewage Treatment Plant, NY. In the case of the Fort Bragg treatment plant, the filter rocks were replaced with larger rocks. A new RBC system was then added after the filter to meet the new NPDES secondary treatment permit standards. The renovated filter serves as a roughing filter to reduce the BOD_5 load to the RBC system and therefore, reduces the size of the RBC system.

Renovation work is minimized, since there is no need to build a new drainage and media support system. The degree of improvement in filter treatment performance is not critical, since the new RBC system is designed to take on the remaining BOD_5. In the case of the Suffern Municipal Sewage Treatment Plant, the filters are renovated and also serve as roughing filters primarily for BOD_5 removal. However, in this case, the degree of improvement in filter treatment performance is critical. A 50 percent BOD_5 removal by the two renovated filters is required, since the activated sludge process for BOD_5 removal and nitrification must be added onto the treatment plant when space is very limited. To obtain 50 percent BOD_5 removal, simply replacing the rocks with new rock media is not adequate. Consequently, after a pilot plant study, a design with plastic media was adopted. Renovation work was more extensive, involving construction of a new drainage and media support system, filter well, replacing the rock media with plastic media, adding a plastic dome, and adding a forced aeration system for each filter.

Although the scope and method of filter renovation vary among plants, the objective of cost savings is the same at all locations.

Filter Operation

The operation of a plastic-media filter is not much different from that of a rock filter.* Roughing filters and polishing filters are exceptions:

1. A roughing filter would remove only 40 to 60 percent of the filter influent BOD_5.

2. For secondary treatment, a polishing filter is expected to remove a much lower percentage of BOD_5 from the filter influent in comparison to a trickling filter.

3. The final product of a roughing filter and even for most trickling filters designed for secondary treatment does not contain much nitrate unless nitrification is designed for.

4. Oxygen saturation levels should not be expected in the roughing filter effluents.

5. Although recirculation is used to increase the removal of BOD_5 and solids, it also ensures that at low-influent flow conditions, there is enough hydraulic load (influent plus recirculation) to wet the entire filter bed. A dry filter surface over a period of 1/2 day or longer may kill the biomass, thus decreasing performance for part of the filter. The minimum wetting rate (hydraulic load or hydraulic application rate) recommended by various manufacturers varies from 0.2 to 0.5 gpm/sq ft.

The practice of recirculation varies among plants. At the trickling-filter plant of Seneca Army Depot, a relatively constant recirculation flow, due to a constant head tank device of 0.59 mgd combined with a varying influent flow rate (average 0.18 mgd), results in a changing recirculation ratio. The average recirculation ratio is 0.59/0.18 = 3.25, which is high compared to most other trickling-filter plants. The filter has a media depth of only 3 ft and is easily one of the shallowest filter facilities in the United States. A high recirculation ratio is required to increase the detention time and equalize the effluent quality which the plant has been successfully doing since the filter was renovated. At the Fort Lewis plant, the filtered effluent is split, with part of it going back to a wet well. The wet well level is controlled by an automatically operated butterfly valve, which controls the amount of trickling-filter effluent recirculation to the pump station. There are three pumps in the wet well with capacities of 11 mgd, 11 mgd, and 5.9 mgd, respectively, to pump the combined influent and recirculated flow to the filters. The present scheme of operation is to use two pumps delivering about 15 mgd from the wet well (the third pump serves as a backup), regardless of the influent flow. The average influent flow is about 5 mgd, resulting in

---

*Chapter 5 of Army Technical Manual 5-665, Trickling Filters, Operation and Maintenance of Domestic and Industrial Wastewater Systems (January 1982), describes normal operations.

a recirculation ratio of 3.0. During dry seasons, the average influent flow may be 3.5 mgd, and during wet seasons, due to infiltration-inflow of the sewer line, the average influent flow may be as high as 10.0 mgd. Nevertheless, the hydraulic loading is kept relatively constant at 15 mgd. Therefore, the recirculation ratio ranges from 0.5 to 4.3, being high at low influent flows and low at high influent flows.

Since infiltration-inflow sometimes causes high flow and diluted BOD_5 concentrations at the Fort Lewis plant, a low recirculation ratio is adequate with the high hydraulic loading and no increase in BOD_5 load. At low flows, this operation results in high recirculation; however, a high recirculation rate is not required even though the BOD_5 concentration of the influent is higher, because the mass BOD_5 loading has not increased. It is possible to cut back the recirculation rate to save power and the pump, with the 5.9 mgd capacity pump used less often. However, such action demands more operator attention and time. For simplicity of operation, the present scheme which uses a constant hydraulic loading to the filters is justified, even though the power requirement is higher, since low-cost hydroelectric power is used in the Fort Lewis area. However, in regions with higher power cost, cutback of recirculation at low influent flows should be considered unless the influent BOD_5 concentration is very high.

Like the Fort Lewis treatment plant operation, the RCA Corporation plant at Mountaintop, PA, also uses a constant hydraulic loading applied to the trickling filter. Consequently, the same analysis applies to both cases. The Suffern Municipal Sewage Treatment Plant has a chamber to store the filtered effluent. A pipeline with a float-operated butterfly valve connects the storage chamber to the wet well of the pumping facility. When the influent flow is high, the water level in the wet well rises. Therefore, the flow from the storage chamber to the wet well will decrease. However, the rate of pumping is kept relatively constant at 1800 gpm (average plant influent is 1.5 mgd or 1050 gpm, but varies from 0.6 to 2.5 mgd). This, in effect, results in a lower recirculation at high influent flow and vice versa. The recirculation ratio varies, but on the average is 1.5 to 1.7.

It can be seen that the method of recirculation varies from plant to plant. Basically, however, a relatively constant hydraulic loading applied to the filter is attempted while the influent flow varies. The resulting recirculation ratio (increases with lower influent flow and vice versa) seems to work well for all plants. As in the Fort Lewis treatment plant, a lower recirculation flow can be used at low influent flow, provided that the minimum wetting rate of the filter is met. However, the more sophisticated control and greater demand of the operator's attention may outweigh the benefit of the savings in power cost. Nevertheless, such operation may be advantageous for large treatment plants. Over the long run, the savings in power cost could be substantial if the recirculation could be reduced at low influent flow.

Cost of Filter Construction and Renovation

This section presents the costs of trickling-filter construction and renovation. For comparison, a 1.0-mgd trickling-filter facility, including the filter with plastic media and a pumping station designed for 85 percent BOD_5 removal (BOD_5 removal from 200 mg/L to 30 mg/L) is designed with various

combinations of filter diameter, filter depth, and recirculation ratio. The facility construction and power costs are analyzed. The cost analysis is useful for identifying the important cost elements and how these cost elements would affect the total cost of the filter facility at the various combinations of diameter, depth, and recirculation ratio. These costs are also compared with a conventional rock filter facility. Finally, filter renovation cost is analyzed. The cost savings of filter renovation over constructing a new trickling-filter facility are provided.

New Filter Construction

To estimate the cost of a new filter construction, certain wastewater characteristics and operational conditions are assumed in the following:

Influent flow = 1 mgd = Q

BOD_5 removal = 85 percent (from 200 mg/L to 30 mg/L)

K-rate constant = 0.06 in the Eckenfelder Equation with recirculation

$$\frac{L_e}{L_o} = \frac{e^{-KD/q^{0.5}}}{(1+R) - R \cdot e^{-KD/q^{0.5}}}$$

in which q is expressed in gpm/sq ft, D is media depth, and R is recirculation ratio; L_e and L_o are, respectively, effluent and influent BOD_5 concentration.

Using the operational conditions given above and any specified filter depth and recirculation ratio, one can calculate the hydraulic load, q, using the formula:

$$q = \frac{(KD)^2}{\left\{ \ln \left[\dfrac{(1+R)\dfrac{L_e}{L_o}}{1+R\left(\dfrac{L_e}{L_o}\right)} \right] \right\}^2} \qquad \text{[Eq 31]}$$

From the q value, one can calculate the surface area of the filter as A = Q/q. It follows that the media volume can be calculated as V = DA. This procedure is used to calculate the media volume required for various selected media depths and recirculation ratios. The results are plotted in Figure 30. It indicates that for any given recirculation ratio, the media volume required for 85 percent BOD_5 removal decreases with increasing media depth. For example, for R = 3.0, 10,000 cu ft of media are required to obtain 85 percent BOD_5 removal at a media depth of 8 ft; however, for the same recirculation ratio and at a media depth of 16 ft, only 5000 cu ft of media volume will be required to obtain 85 percent BOD_5 removal.

The cost of filter construction is estimated based on the following unit costs given by various manufacturers and also partially adjusted based on the bid price of one project under construction.

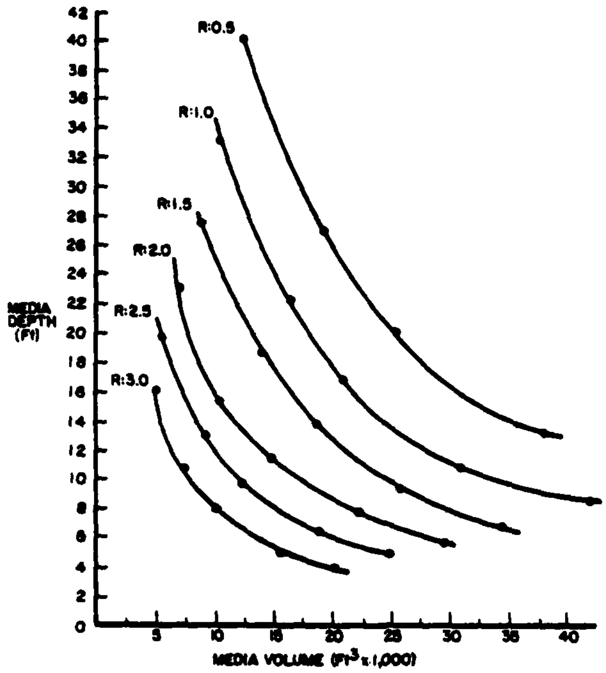


Figure 30. Media depth vs. media volume.

Plastic media	$4.0/cu ft
Filter foundation drains	$12.0/cu ft
Rotary distributor	$400/ft of diameter
Excavation	$1.75/cu yd
Filter wall	$10.0/sq ft
	Installed Price
Munters, Biodek	$4.0 cu ft
B. F. Goodrich, Vinyl core	$3.55 cu ft depending on shipping distance
American Surfpac, Surfpac	$7.0/cu ft for small quantities (1000 cu ft) $2.75/cu ft for large quantities (1/2 million cu ft)
Norton, Actifil	$3.10 cu ft (depending on shipping distance)
Koch, Flexipac, and Flexirings	No information

Using these unit costs, the installed filter costs for five different filter diameters are calculated and plotted (see Figure 31). It is apparent that the installed filter cost increases with media depth as well as with filter diameter. Installation costs are much lower for filters with smaller diameters and do not increase with media depth as fast as for the large-diameter filters. For example, a 20-ft-diameter filter could have a media depth from 17 to 40.5 ft, using recirculation from R = 3.0 to 0.5, respectively, to obtain

85 percent BOD_5 removal. The installation cost would range from $45,000 to $91,000. By comparison, an 80-ft-diameter filter could have a media depth from 4.3 to 10 ft, using R = 3.0 to 0.5, respectively, to achieve the same 85 percent BOD_5 removal. However, the installation cost would be much higher, increasing significantly from $240,000 to $382,000.

Besides the filter installation cost, the pumping facility, including pumps and control as well as a small wet well, are also a significant portion of the total trickling-filter system cost. Information on costs for various sizes of pumps for filters of different depths is available from EPA publications.[24] Figure 32 shows the pumping facility construction costs associated with various media depths and filter diameters. Two interesting relationships are observed. First, the cost increases with decreasing media depth for a given filter diameter. To keep an 85 percent BOD_5 removal, the recirculation ratio must be increased and the media depth decreased. Consequently, a larger pumping facility is required and, therefore, a higher installation cost. Also, the pumping facility cost increases rapidly as the diameter of the filter decreases. As Figure 30 shows (e.g., with R = 0.5), the pumping facility installed cost is $85,000 for an 80-ft-diameter filter (10.25-ft media depth) and $110,000 for a 20-ft-diameter filter (40.5-ft media depth). Obviously, a small filter must be much taller in order to obtain the same BOD_5 removal, resulting in a much higher head requirement for the pumping facility and a higher construction cost.

The total installation cost of the trickling-filter system is made up of the filter installation cost and the pumping facility installation cost. Figure 33 plots the total cost versus media depth. As indicated by Figure 33, the pumping facility cost affects the total cost more for small but taller filters than for larger but lower filters. When the cost is spread between different sizes of filters, it is reduced, but not significantly (comparing Figure 32 and Figure 33). It is also noted that smaller but taller filters are less expensive. More importantly, the increase of media depth for the 20-ft-diameter filter results in only a slight increase in total system cost. Although some cost savings can be realized by reducing the media depth but increasing recirculation, there is no reserve capacity for the filter operation if a high recirculation rate is required all the time; i.e, the opportunity of further increase of recirculation to take on peak BOD_5 loads is very limited. Considering the practical media depth for tall filters as 30 ft, the required recirculation ratio for the 20-ft-diameter filter is 1.2 (interpolation) according to Figure 33. If the media depth is reduced to 16 ft and the recirculation ratio increased to 3.0, for the same filter, the total cost difference is $193,000 - $170,000 or $23,000. The taller filter, although more expensive, requires a recirculation ratio of only 1.2, which can be further increased to receive a much higher BOD_5 loading, if necessary. The same operation is not considered suitable for the taller filter, because any recirculation increase will exceed R = 3.0, which is considered the practical limit of recirculation by most design engineers. Daily operation with high recirculation also requires more power, which adds to the operating cost.

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[24] Capital and Operating Costs of Pollution Control Equipment Modules, Vol 2, Data Manual, EPA-R5-73-0236 (USEPA, July 1973); Innovative and Alternative Technology Assessment Manual, CD-53 (USEPA, February 1980).

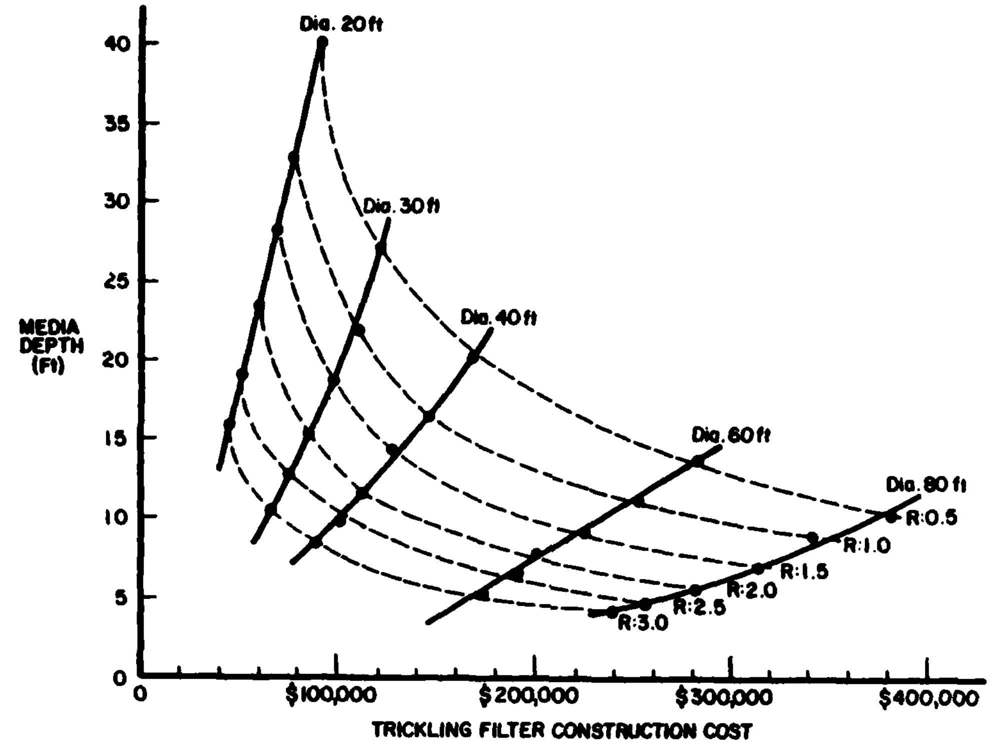

Figure 31. Media depth vs. trickling-filter construction cost.

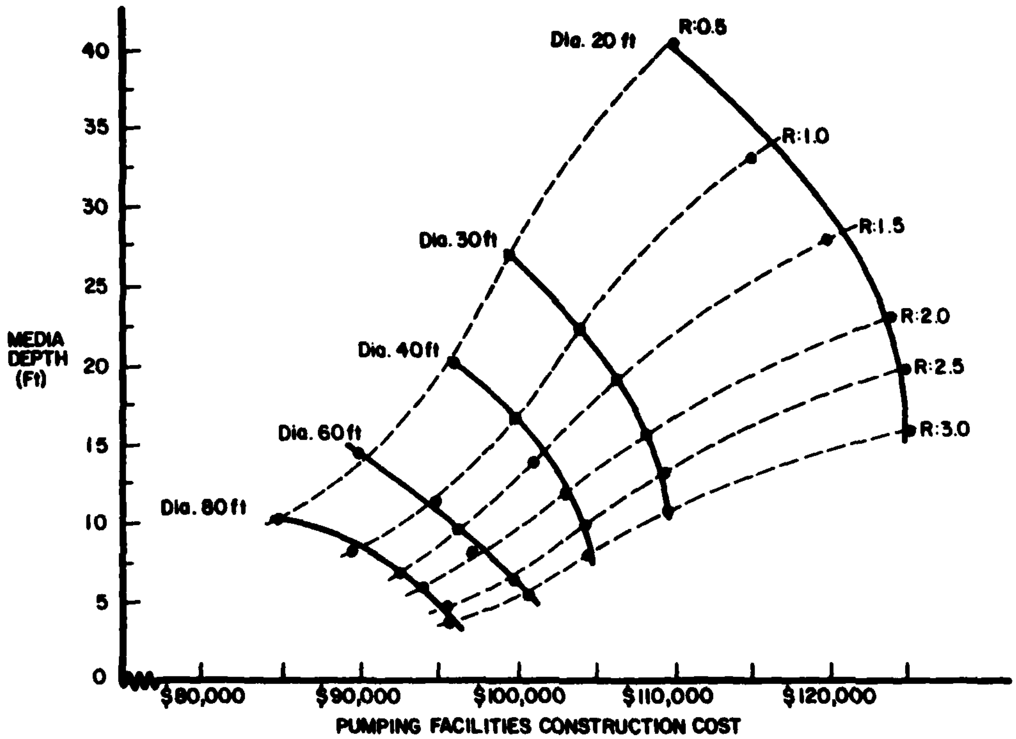

Figure 32. Media depth vs. pumping facilities construction cost.

Power cost varies according to the power demand, which is calculated as follows:

$$\text{kW} = \frac{Q(1+R)\text{mgd} \times (694\text{gpm/mgd}) \times (\text{media depth} + 6\text{ ft}) \times 0.746\text{ kW/hp}}{3960\ \frac{\text{ft gal}}{\text{min hp}} \times 0.67}$$

where 0.67 is the assumed pump and motor efficiency and 6 ft is the assumed depth of the underdrain system plus the distributor height above the media.

Power cost is calculated by assuming a unit cost of $0.1/kWh.

Power cost/yr = kW x 24 hr/day x 365 day/yr x $0.1/kWh.

Figure 34 gives the results of the power cost estimation. It is obvious that power cost is higher for smaller but taller filters for any of the recirculation ratios used. However, it is interesting to note that for small filters with 20- to 30-ft diameters, the increase in power costs with higher Q values does not apply beyond R = 2.0. This is because the power demand for increasing R is balanced by the decrease in media depth.

Combining the information from Figures 33 and 34, an economic evaluation of the alternatives can be made for treating a 1.0-mgd wastewater flow and obtaining 85 percent BOD_5 removal. Using Figure 33, the initial construction cost for the trickling filter and required pumping facility can be found for a specific diameter of trickling filter and depth. Then, using Figure 34, the approximate pumping cost per year can be found by locating the diameter, depth, and recirculation ratio and then the corresponding pumping cost per year.

Following is an example of economic evaluations for a 10-year period:

Trickling-filter diameter	20 ft
Trickling-filter height	40 ft
Required recirculation ratio (From Figure 33)	0.5
Construction cost (From Figure 34)	$200,000
Power cost per year	$12,000
Power cost x 10 years	$120,000
Total cost = $200,000 + $120,000 =	$320,000

Trickling-filter diameter	20 ft
Trickling-filter height	22 ft
Required recirculation ratio (From Figure 33)	2.25
Construction cost (From Figure 34)	$180,000
Power cost per year	$15,500
Power cost x 10 years	$155,000
Total cost = $180,000 + $155,000 =	$335,000

As shown in Table 34, which gives a 10-year economic evaluation of different size trickling filters, the filter that costs the least to build initially may cost more in the long run because of its higher power requirements.

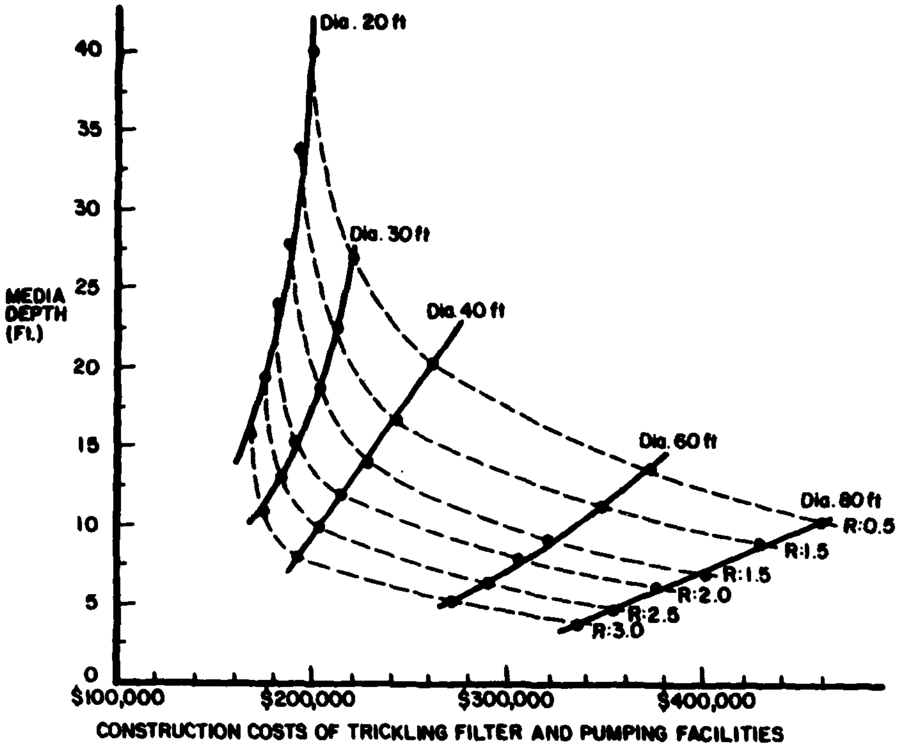

Figure 33. Media depth vs. construction costs of trickling-filter and pumping facilities.

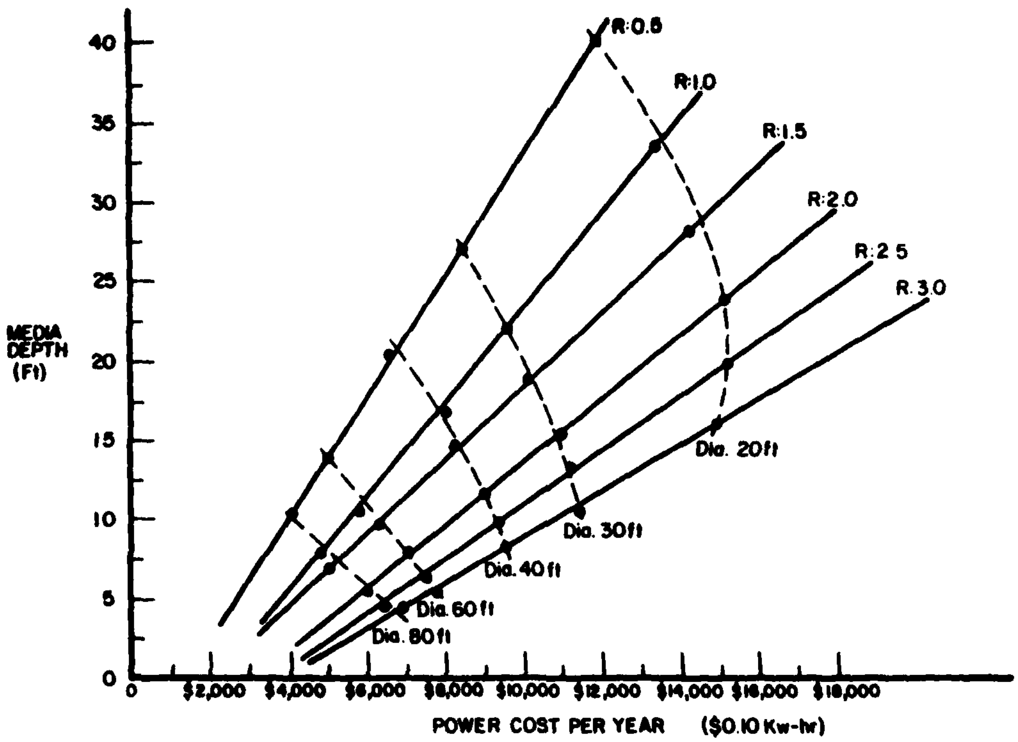

Figure 34. Media depth vs. power cost per year.

Table 34

A 10-Year Economic Evaluation
of Different Sizes of Trickling Filters

Trickling Filter Diameter	Media Height	Required Recirculation Ratio	Construction Cost ($)	Power Cost Per 10 Years ($)	10-Year Construction and Power Costs
20	40	0.5	200,000	120,000	277,367
20	22	2.25	180,000	155,000	279,928
20	16	3.0	170,000	150,000	266,705
30	27	0.5	220,000	85,000	274,800
30	18	1.5	205,000	100,000	269,470
30	11	3.0	175,000	115,000	249,140
40	20	0.5	260,000	66,000	302,550
40	10	2.5	205,000	94,000	265,602
40	8	3.0	195,000	95,000	256,246
60	12.5	0.75	360,000	55,000	395,458

However, this varies, depending on the actual energy use for a particular filter and the price of energy in the period of the useful life of the system. For 1 mgd plants with 85 percent BOD_5 removal, it is suitable to build a 30-ft-diameter filter with 27-ft media depth and operate it with a 0.5 recirculation. The 10-year total cost is only $15,000 more, but leaves much room for increasing the recirculation to accommodate higher BOD_5 loadings.

Simple Filter Renovation

Filter renovation usually involves replacing rock media with plastic media because the latter are much more effective. The amount of work and cost varies among plants depending on how much renovation is required to obtain the required amount of treatment upgrading.

Example 1. The Seneca Army Depot Treatment Plant #4 is an example of filter renovation requiring minimal work and cost.

1. Objective: To upgrade an existing 0.25-mgd rock filter (50-ft diameter and 3-ft bed depth) to achieve secondary treatment.

2. Renovation: Remove the rock media; install an aluminum grating above the existing filter floor; install plastic filter media up to the original level; replace the bearings of the existing rotating distributor; install a new aluminum dome over the filter; provide simple alteration of the recirculation pipe arrangement to increase the recirculation flow.

3. Renovation Cost: $100,000.

4. Discussion: The condition of the trickling filter before renovation was not bad, but treatment performance was below the secondary treatment standard. Consequently, the filter wall, filter underdrain system, and rotary distributor were all retained, which saved a great deal in demolition and excavation costs. New items required were the aluminum grating, the plastic media, and the dome. Except for the dome, the renovation work required was minimal.

Another plant in the Seneca Army Depot which was almost identical to plant #4 was completely abandoned. Instead of renovating this plant, a new RBC facility was built at a cost of $2.5 million. However, it should be noted that the difference between $2.5 million and $100,000 does not accurately represent the potential savings of renovation. The new RBC plant includes nitrification as a tertiary treatment step. The renovated trickling filter does not provide nitrification and must rely on the wetland for tertiary treatment. Consequently, this difference in treatment capability must be considered to provide an equitable cost-effectiveness comparison, and two different comparisons of cost-effectiveness are presented.

a. Estimate the cost of nitrification for STP #4, subtract this cost from the $2.5 million total cost to obtain an estimate for a new RBC plant with secondary treatment only. This cost estimation can then be compared with the $100,000 renovation cost to see the potential savings.

Cost of nitrification (0.25 mgd)	
Suspended growth reactor and clarifier	$0.24 million
or RBC, no separate clarification required	$0.20 million
Cost of dual media filtration following clarification (complete system)	$0.17 million

The cost of a new RBC plant for secondary treatment installed in 1980 would be:

$$2.5 - (0.20 + 0.17) = \$2.13 \text{ million}$$

Renovation of the trickling filter to upgrade the plant to achieve the same degree of treatment is $100,000.

Cost savings = 2.13 - 0.1 = $2.0 million.

b. Estimate the cost of a new trickling filter to replace the existing filter. This cost is then compared with the renovation cost. Building a new trickling filter instead of building a whole new plant is more realistic and practical for most Army facility upgrading.

Cost of a new trickling filter (excluding clarification)	$0.12 million
Cost of an aluminum dome for the renovated filter	$0.05 million
Cost of recirculation and other pipeline modification	$0.08 million
Total cost =	$0.25 million

Cost savings = 0.25 - 0.1 = $0.15 million

These cost estimations were obtained from the EPA's Innovative and Alternative Technology Assessment Manual and adjusted to 1980 dollars for direct comparison.

The most recent unit costs of filter construction have been used to provide the following for replacing a rock filter with a plastic media filter:

Media	$23,500
Rotary distributor	24,000
Side wall	17,500
Foundation, underdrain	35,000
Dome	50,000
Pumping facility	75,000
Total	$225,000

The cost, when adjusted to 1980 dollars, is $194,000, so the cost savings = 0.194 - 0.1 = $0.094 million.

Thus, renovating the filter at a cost of $100,000 instead of building a new RBC plant can save about $2.0 million. Even the other option of renovating instead of building a new trickling filter saves $0.094 million, or 48 percent.

Example 2. Another example of simple renovation work to upgrade a filter plant is the RCA Treatment Plant at Mountaintop, PA.

1. Objective: To upgrade an existing 0.58-mgd rock filter (52-ft diameter and 6-ft bed depth) to achieve secondary treatment.

2. Renovation: Remove the rock media; rebuild the underdrain system; fill in plastic ring media randomly; rebuild the center bearing assembly of the rotating distributor; modify the pump facility.

3. Renovation Cost: Renovation work involved not only the trickling filter, but also adding a sulfuric acid storage tank, a new chemical feeding system, six auxiliary pumps, two flow meters, two chart recorders, one stream-monitoring station, three aerators (7 1/2 hp each) for the lagoon system, and one sludge drainage system for the lagoon. The total cost was $440,000 in 1975. However, no breakdown of the costs for each item was available.

If a new filter with plastic media and a pump facility were built today, the following costs would apply:

Media	$ 50,100
Pump facility	112,500
Foundation and underdrain	35,500
Rotary distributor	25,000
Excavation	1,000
Sidewalk	20,000
Total	$244,100

Renovation for the filter system would probably cost:

Media	$ 50,100
Pump facility modification	56,000
Foundation and underdrain	35,500
Miscellaneous (replace bearing piping, remove rock media, etc.)	8,000
Total	$149,600

Possible cost savings = 244,100 - 149,600

= $94,500

The cost savings are substantial because, as with the Seneca Army Depot Treatment Plant example, the renovation is not extensive.

Extensive Renovation

The Suffern Municipal Sewage Treatment Plant is an example of a trickling filter going through extensive renovation as a part of the treatment plant upgrading project (see Chapter 5).

1. Objective: To upgrade two existing rock filters of a design flow of 1.9 mgd (each filter has a 40-ft diameter and about a 6-ft media depth) to serve as roughing filters removing 50 percent of the incoming BOD_5. Filtered effluents are further treated with an activated sludge process for carbonaceous BOD_5 removal and nitrification.

2. Renovation: Remove the rock media; remove the side walls; completely rebuild the underdrain system; modify the center column and rotary distributor system; install plastic media; add a plastic dome to each filter; remove the existing pumping facility and build a new one for replacement.

3. Renovation Cost: The renovation cost is $234,000 for the filters and $129,000 for the new pumping station, for a total of $363,000.

The filter renovation work is so extensive that only the original filter floor and rotary distributor remain in each filter; everything else is new. For cost comparison, a new plastic-media filter is designed for the same purpose (i.e., to remove 50 percent of the BOD_5) with a diameter of 60 ft and a media depth of 6 ft. The new filter is to be operated at a recirculation ratio of 1.0. The cost estimate is:

Media	$ 65,000
Foundation and underdrain	60,000
Rotary distributor	32,000
Side wall (precast concrete panels)	20,000
Dome	35,000
Demolition and removal	35,000
Pump station	120,000
Total	$367,000

The estimated cost is almost identical to the renovation cost of the two filters. The recirculation ratio for this alternative of one new filter is 1.0, which is lower, on the average, than the two renovated filters at Qr/Q = 1.6. Therefore, the power requirement is smaller for one new filter, which is a slight advantage over the long run.

Another alternative is to design and build a 40-ft-diameter plastic-media filter. The filter would have a 10-ft media depth and use a recirculation ratio of 0.5 for 50 percent BOD_5 removal. The cost estimate is:

Media	$ 50,000
Foundation and underdrain (modifying existing)	15,000
Rotary distributor	16,000
Side wall (precast concrete panels)	25,000
Dome	25,000
Demolition and removal	30,000
Pump station	120,000
Total	$281,000

Compared to the case of two renovated filters or the case of one new filter having a 60-ft diameter, this latest alternative (the 40-ft-diameter filter) is the least expensive in terms of installation costs. The power requirement is also the lowest because the recirculation ratio is 0.5, even though a higher head of pumping is required. More specifically, the power requirement is

$$\frac{0.5(10 + 6)}{1.6(6+6)} \times 100 = 42 \text{ percent of the power requirement of operating the two renovated filters.}$$

This analysis shows that filter renovation is not necessarily always the most cost-effective strategy. Since BOD_5 removal with deep filters can be more efficient, building a new filter can be more cost-effective.

Table 35 summarizes the three cases of filter renovation.

Table 35

Summary of Filter Renovation Data

Plant	Size of filter and Extent of Renovation	Renovation Cost	Estimate Cost of a New Filter and Pump Facility
Seneca Army Depot Romulus, NY	0.25 mgd 1 filter, 50-ft diameter; 3-ft media depth; simple renovation.	$100,000 (1980)	$194,000 (1980)
RCA Corp. Sewage Treatment Plant, Mountaintop, PA	0.58 mgd 1 filter, 52-ft-diameter; 6-ft media depth; simple renovation	$149,600 (estimated) (1983)	$244,100 (1983)
Suffern Municipal Sewage Treatment Plant, Suffern, NY	1.9 mgd 2 filters, each 40-ft-diameter, 6-ft media depth; extensive renovation	$363,000	$367,000 (60-ft diameter, 6-ft media depth) $281,000 (40-ft-diameter, 10-ft media depth)

7 GUIDELINES FOR CHOOSING SYNTHETIC-MEDIA TRICKLING FILTERS

This chapter discusses the applicability and the limitations of synthetic-media tricking filters in Army installations. Guidelines are presented for determining the circumstances in which a synthetic-media trickling filter should be chosen over other types of treatment technology, such as activated sludge, RBC, etc. Costs and O&M requirements are considered in the decision-making procedure. Research needs for Army application are also discussed.

Synthetic-Media Trickling Filters for Army Applications

There are a large number of trickling-filter treatment plants at Army installations. Almost all these filters have shallow beds containing rocks or other natural filtering media. They are simple to operate and maintain, but they occupy a great deal of land space. Filter fly problems are common, and some plants experience odor problems.

Starting in the 1950s, other types of treatment processes were used more often, including activated sludge, RBC, oxidation ditch, land treatment, and lagoons. Rock or other natural filtering media are characterized by heavy dead weights, small void space between media, and small specific surface area (sq ft/cu ft of media volume); this requires shallow filters with large surface area (e.g., land space) to provide enough ventilation and media surface for growth. The development of plastic filtering media has allowed the construction of trickling filters which do not have the disadvantages associated with rock filters. Taller filters with lightweight construction require less media volume and result in a highly cost-effective treatment system using the plastic media. Between 1979 and 1981, many installations began using plastic media. As described in Chapter 4, facilities constructed as early as 1974 are working as designed without any major problems.

Most of the plastic-media trickling filters are for carbonaceous BOD_5 removal. Some are roughing filters which use another trickling filter to complete the secondary treatment BOD_5 removal requirement, while others use other biological treatment processes for further BOD_5 removal. Some filters are used for combined BOD_5 removal and nitrification, and some are used only for nitrification. The design equations outlined in Chapter 6 are considered adequate today.

Recently, the EPA has accepted trickling filters as a secondary treatment process. This, plus the fact that plastic-media filters have been used for carbonaceous BOD_5 removal-nitrification or nitrification alone has demonstrated how successfully synthetic-media filters can be applied to secondary or tertiary treatment. The Army has used them successfully at Fort Lewis, WA, and at Seneca Army Depot, NY. Fort Lewis installed new filters to achieve secondary treatment, and Seneca Army Depot renovated its rock filter to a plastic-media filter to upgrade treatment performance. Although Army experience with plastic-media trickling filters is limited (7 to 8 years for Fort Lewis and 2 years for Seneca Army Depot), the successful record of synthetic

media, along with the longer history of successful use in municipal and industrial treatment plants (since 1961) should be a strong inducement for Army engineers to consider similar applications.

Unlike the RBC system, which consists of plastic media mounted on a rotating shaft, the plastic media in a trickling filter is fixed in position. Consequently, the potential problems of shaft failure or media falling off do not exist in trickling filters. This provides an incentive to choose plastic-media trickling filters over an RBC system.

Before outlining a procedure for choosing between plastic-media filters and other competitive treatment processes, it is necessary to discuss first the limitations of the process.

Limitations of the Plastic Trickling-Filter Process

Effluent Quality

Most biological treatment processes, including activated sludge, are not efficient in treating low-BOD_5 wastewaters. After a certain proportion of BOD_5 is removed from domestic wastewater, the remainder is very hard to remove. The same phenomenon is observed with plastic-filter media.[25] It appears that each type of waste has a specific equilibrium BOD_5 which also depends on the type of treatment process. The equilibrium BOD_5 concentration for trickling filters, both for rock media or plastic media, is usually higher than that for the activated-sludge process; i.e., the activated-sludge process effluent is usually superior to that of the trickling filters, even though trickling filters can meet the 30-day average of 30 mg/L BOD_5 or 85 percent BOD_5 removal if properly designed and operated. Where NPDES permits require effluent BOD_5 concentrations much below 30 mg/L, trickling filters with plastic or rock media are not suitable.

The Uncertainty of the Rate Constant K-Value

When municipal wastewater is treated, it is common for design engineers to use a K-value of 0.06 to 0.08 in the design equation. The K-value reflects the treatability of the wastewater. However, the wastewater characteristics and therefore its treatability varies among Army facilities, and it may differ greatly from a typical municipal wastewater. The K-value is reduced with an increasing fraction of industrial waste which contains refractory organics that are resistant to biological treatment. Unless the fraction of industrial waste at the Army installation is very small (e.g., less than 10 percent by flow and by mass of BOD_5, it is not certain what K-value would be appropriate for the design. Selection of too high a K-value would lead to under-design (filter too small), and a K-value that is too low would lead to over-design (filter too big). A pilot study following the procedure described in Chapter 6 can be used to evaluate the K-value of a specific site's waste.

[25] J. E. Germain, 1966.

Structural Integrity of the Media

The dry weight of plastic media is about 2.2 lb/cu ft, and with the wet biomass, the weight increases to 4.7 lb/cu ft. However, all plastic modules could take on loads of 30 lb/sq ft per foot of media depth and a bearing capacity of 400 lb/sq ft or greater and are therefore self-supporting. Similar information on plastic media in ring structures is not available. Since random-fill is used in packing the media, the wet weight with biomass on the ring structure in pounds per cubic foot is also difficult to estimate.

All trickling filters packed with random-fill ring media experience some settlement: shallow filters several inches to 1 ft, and tall filters (25-ft tower) up to 6 ft. It is not known whether the settlement is a natural phenomenon over time (repacking) or the result of deformation at the bottom caused by the weight above. Since no broken pieces have ever been found, it is inferred that the rings do not break. Although there is no report on interruption of wastewater or air flow because of media settlement, one plant that has a lot of chemical precipitation in the filter needs to be backwashed once a week to keep the voids opened. It is reasonable to expect that the settlement is more significant for deep filters, thus presenting a potential plugging problem. For this reason, deep filters and large plastic modules are preferred. Settlement of ring-structure media always requires adding more media to the original top level to provide the specified media volume. Refill may be required several times, since some deep filters have settlement over a period of several years.

Choosing Between Plastic-Media Filters and Other Competitive Treatment Processes

Two situations are considered: (1) Army treatment plants having rock filters that need upgrading, and (2) installations that need to construct a new secondary treatment plant or upgrade a plant that is not equipped with trickling filters.

Upgrading Existing Rock Filtering Plants

Since many of the Army's trickling-filter plants with rock media need upgrading, it is important to know if plastic-media filters will be effective for these applications. Several advantages of renovation include maximum use of the existing treatment plant units, maximum cost-effectiveness, and no additional operator training required. However, these advantages will be lost if any treatment process other than plastic-media filter is selected.

Upgrading Plants Without Filters or Building New Treatment Plants

In this case, the choice between plastic-media filters and other competitive treatment processes can only be made after the following factors are considered and carefully weighed: cost-effectiveness of each process, reliability in performance, energy requirements, required operating skill, and land requirements. Tables 36-39 compare biological processes in each of these categories. Table 40 lists the various decisions which must be made to respond to different conditions of the trickling filters.

Table 36

Average Performance Reliability of Biological Processes

Process	Percentage Removal		Ranking
	TSS	BOD_5	
Activated sludge (conventional)	81	84	2
Trickling filters	82	79	3
RBC	79	78	4
Oxidation ditch	94	93	1

Table 37

Ranking of Energy Requirements for the Biological Processes

	Plant Capacity (mgd)					
	0.5	1.0	5.0	10.0	EPA Data	Overall Rank
Trickling filter	1	1	1	1	1	1
RBC	3	2	3	2	2	2
Activated sludge	4	4	4	3	4	4
Oxidation ditch	2	3	2	4	3	3

Table 38

Ranking of Biological Processes for Operational Skills Required

	Ranking for Operational Skill
Trickling filter	1
RBC	3
Activated sludge	4
Oxidation ditch	2

(Based on all plant capacities from 0.5 through 10 mgd.)

Table 39

Overall Ranking of Biological Processes

	Total Score	Overall Ranking
Trickling filter		
Plastic	29	3
Rock	24	2
RBC	44	5
Activated sludge	37	4
Oxidation ditch	21	1

Table 40

Recommended Action or Decision Alternatives in Upgrading Existing Trickling Filters

Condition of Existing Filters	Renovation Work Required	Recommended Alternative Actions or Decisions
Rock filter in working condition, but hydraulic and/or organic loads exceed design loads. Effluent quality needs upgrading, or expansion of treatment capacity is required.	Not extensive (Example: Seneca Army Depot, NY; RCA Corporation, Mountaintop, PA)	1. Remove rock media; renovate underdrain system if required; refill filter with plastic media; renovate recirculation pump facility and rotary distributor if required. 2. If calculation shows above action not meeting upgrading requirements, supplement by increasing filter wall and media depths. 3. Leave existing trickling filter intact. Add a new plastic media filter as a roughing filter or a polishing filter.
Rock filter in poor working condition; filter structure deteriorating; effluent quality needs upgrading; hydraulic and/ or organic loads exceed design loads.	Extensive (Example: Suffern Municipal Plant, NY)	4. Repair and renovate filter; replace rock with plastic media (similar to actions 1 and 2 but more extensive). 5. Remove existing trickling filter; build new filter with plastic media. Choose between actions 4 and 5, depending on cost-effectiveness analysis.

General Recommendations: 1. New filter should be able to operate in parallel or in series with existing filters, increasing the backup capacity of the secondary treatment unit. 2. Filter cover (dome) can be added in cold climate region or where it is desired to minimize odor, filter fly, and aerosol problems. 3. Random-fill plastic media should be used in shallow filters only.

The competitive treatment processes to be considered include activated sludge, trickling filters with rock or plastic media, rotating biological contactor, and oxidation ditch. Only the secondary portion of each treatment process is compared; the rest is assumed to be identical. That is, regardless of the process, the requirements and costs associated with preliminary/primary treatment are identical, including primary clarifier, sludge collection and treatment, sludge disposal, and effluent disinfection. The exception is the oxidation ditch, where primary clarifiers are not required. Consequently, the cost of primary clarifiers is subtracted from the oxidation ditch treatment process to obtain the comparable secondary treatment cost. Land treatment and lagoon treatment are not included because their system requirements and achievable levels of treatment are quite different from the others.

Tables 41 through 44 summarize the construction and O&M costs for each of the competitive secondary treatment processes. Secondary treatment means biological removal of carbonaceous BOD_5, final clarifier, and sludge or effluent return facility if necessary. All costs are adjusted to Engineering Index 3725 for comparison on the same-year basis.

For the range from 0.5 mgd to 10 mgd capacity, the construction cost for the oxidation ditch is consistently the lowest, followed by activated sludge, trickling filter, and RBC. The cost differential between plastic-media filters and activated sludge is not large and, in fact, is insignificant for small plants.

Table 41

Construction Costs and O&M Costs for Selected Waste Treatment Processes at 0.5-mgd Plant Capacity

(Cost in Millions of Dollars)

Process	Labor (Annual)	Materials (Annual)	Power (Annual)	O&M (Annual)	Total Construction Cost	O&M Cost Ranking	Cost Ranking
Trickling Filter Plastic Media	0.0143	0.00552	0.00149	0.0213	0.4854	1.5	3.5
Trickling Filter Rock Media	-------------------NOT AVAILABLE-----------------					1.5	3.5
Rotating Biological Contactor	0.0154	0.00459	0.0045	0.0245	0.6457	3	5
Activated Sludge	0.016	0.00856	0.00557	0.0301	0.4455	4	2
Oxidation Ditch			0.003	0.033	0.1387	5	1

Table 42

Construction Costs and O&M Costs for Selected Waste Treatment Processes at 1.0-mgd Plant Capacity

(Cost in Millions of Dollars)

Process	Labor (Annual)	Materials (Annual)	Power (Annual)	O&M (Annual)	Total Construction Cost	O&M Cost Ranking	Cost Ranking
Trickling Filter Plastic Media	0.0170	0.00787	0.0039	0.0288	0.7038	2	3
Trickling Filter Rock Media	0.0163	0.0074	0.0039	0.0276	0.7383	1	4
Rotating Biological Contactor	0.0204	0.00683	0.009	0.0362	1.189	4	5
Activated Sludge	0.0209	0.01283	0.0104	0.04413	0.6905	5	2
Oxidation Ditch			0.01	0.0335	0.1392	3	1

Table 43

Construction Costs and O&M Costs for Selected Waste Treatment Processes at 5.0-mgd Plant Capacity

(Cost in Millions of Dollars)

Process	Labor (Annual)	Materials (Annual)	Power (Annual)	O&M (Annual)	Total Construction Cost	O&M Cost Ranking	Cost Ranking
Trickling Filter Plastic Media	0.044	0.0252	0.012	0.0812	2.3756	3	4
Trickling Filter Rock Media	0.0427	0.0243	0.012	0.079	2.2183	2	3
Rotating Biological Contactor	0.0465	0.0229	0.045	0.1144	2.7097	4	5
Activated Sludge	0.0466	0.04136	0.0452	0.13316	1.9946	5	2
Oxidation Ditch			0.03	0.0685	0.1500	1	1

Table 44

Construction Costs and O&M Costs for Selected Waste Treatment Processes at 10.0-mgd Plant Capacity

(Cost in Millions of Dollars)

Process	Labor (Annual)	Materials (Annual)	Power (Annual)	O&M (Annual)	Total Construction Cost	O&M Cost Ranking	Cost Ranking
Trickling Filter Plastic Media	0.058	0.0656	0.01945	0.143	4.0699	3	4
Trickling Filter Rock Media	0.054	0.0438	0.01945	0.112	3.716	1	3
Rotating Biological Contactor	0.076	0.0414	0.09	0.2074	9.498	4	5
Activated Sludge	0.0713	0.0723	0.0943	0.2379	3.573	5	2
Oxidation Ditch			0.165	0.1155	0.2970	2	1

The ranking is quite different when O&M costs are considered. Trickling filters consistently rank higher than others, while activated sludge ranks much lower. The O&M cost differentials are substantial, and it is easy to see that the total yearly cost (amortization plus O&M cost) is lower for trickling filters than for activated-sludge and RBC processes.

Data on the performance reliability of various competitive biological processes are very limited. According to an EPA report,[26] the average performance of these processes is as shown in Table 36. The performance of these processes is not significantly different, except that the oxidation ditch seems to be consistently better than the others.

The energy requirement varies significantly for the different processes. Tables 40 through 44 show that the energy requirements for operating trickling filters were significantly lower than for RBC, activated sludge, and oxidation ditch. Similar information is found in an EPA publication as shown in Table 37.[27] The required operational skill for these competitive biological processes is rather subjective. However, the O&M costs in Tables 40 through 44 perhaps give some indication that O&M costs increase with operational skill and operator competence. The ranking of all these processes is shown in Table 38.

The land requirements are significantly different, ranging from substantial for oxidation ditch to small for activated sludge. Rock filters and RBC may also require large amounts of space. Plastic-media filters can be built as tall filters and therefore would have no space problem; therefore, land cost is not included in the cost data provided in Tables 40 through 44.

By combining the scores of various rankings given above, the overall ranking shown in Table 39 is obtained. Although oxidation ditches and trickling filters rank higher than activated sludge and RBCs, the importance of each rating factor is not weighed in the ranking process. Therefore, the spread of the score may not be as wide as it is shown above. Nevertheless, the overall score gives a good indication of which treatment process should be viewed more favorably for Army application.

In the final selection, however, some adjustment should be made to the overall ranking given above. Army engineers should judiciously select the treatment technology by taking site-specific requirements into consideration. If, for instance, the existing plant has little extra space for expansion (extra land is available, but the site development cost is substantial), the oxidation ditch process may not be suitable. On the other hand, an activated sludge process may be the choice for a large treatment plant having well-trained operators, or when the NPDES permits require a very low BOD_5 concentration in the effluent (below 15 mg/L). Rock filters have a slight edge over plastic-media filters in overall ranking. However, when circumstances call for a dome over the filter for rigid climate protection, odor and

[26] A Comparison of Oxidation Ditch Plants to Competing Processes for Secondary and Advanced Treatment of Municipal Wastes, EPA 600/2-78-051 (USEPA, March 1978).

[27] W. H. Chester, et al., Review of Current RBC Performance and Design Procedure, for USEPA 68-02-2775.

filter fly control, or for minimizing aerosol problems, a plastic-media filter is a better choice, because smaller domes can be used.

In summary, plastic-media filters should be selected for use under any one of the following conditions:

1. Renovation of existing rock filters.

2. Partial removal of BOD_5 (or a roughing filter) preceding another treatment unit which completes the secondary treatment or beyond.

3. If the most important selection criterion is a minimal energy requirement.

On the other hand, when the NPDES permits require a very low BOD_5 effluent (e.g., below 15 mg/L), trickling filters (rock or plastic media) should not be used.

Research Needs for Army Applications

There is a need to develop the rate constant K-value for plastic-media filter design for Army application. The Army engineer would use a K-value recommended by the media manufacturer only if he/she were certain that the wastewater at the particular site is very similar to a typical domestic wastewater and contains very little industrial waste. Otherwise, a laboratory or pilot study would be required to develop a specific rate constant value. It is feasible for the Army to design and build a mobile unit of plastic-media filter complete with recirculation capability specifically for this purpose.

Another research need would be defining the installation time required for plastic-media filters. The installation time of plastic-media filters is potentially shorter than for other treatment technologies because of its lightweight construction and random-fill media packing. This would be an important factor for Army mobilization.

8 CONCLUSIONS

Trickling filters are among the most Army-amenable wastewater treatment processes. Their reliability, simplicity of operation and maintenance, and low energy consumption are ideal for Army wastewater treatment. Synthetic or plastic media have developed as an improvement to the trickling-filter process and have several advantages over conventional rock-trickling filters, including roughing, secondary treatment, and/or nitrification capabilities. This enables synthetic media to be either a part of or the complete wastewater treatment process for projects ranging from simple renovation to new construction.

As an upgrade or new construction alternative for Army wastewater treatment plants, plastic media have several advantages over conventional rock media which result in a greater efficiency of BOD_5 removal. They provide greater surface area to volume ratio, permit better air flow through the filter bed, decrease the possibility of plugging, and provide a better means of liquid distribution. Plastic media have several other major advantages:

1. Low energy consumption

2. Reliable performance

3. Resistance to hydraulic and organic shockloads

4. Simple operating procedures

5. Effective land use

6. Reduction in sludge bulking problems.

The major disadvantage of plastic media is that they are more expensive than rock media. In addition, they are susceptible to some of the problems associated with rock filters, such as ice buildup in cold climates and nozzle plugging.

Appropriate designs associated with installing plastic media must consider the following parameters: filter sizing and media volume, air requirements, power requirements, the filter bottom, filter tower walls, and nitrification.

The total installation cost of the trickling-filter system is made up of the filter installation cost and the pumping facility installation cost. Estimates of the costs of new filter construction showed that costs increased with increasing media depth for a given filter diameter and that pumping facility costs increase rapidly as the filter diameter decreases. Power costs vary for smaller, but taller filters for any recirculation ratios used. For filter renovation, the amount of work and cost varies among plants, depending on how much work is needed to achieve upgrade. Renovation is not necessarily the most cost-effective alternative since power requirements and BOD_5 removal efficiencies must also be considered.

Operations of plastic-media filters were found to be very similar to those of rock filters; however, roughing filters and polishing filters differ somewhat in the amount of BOD_5 removed, the amount of nitrate in the final product, and the degree of oxygen saturation. Also, tall towers with plastic media usually require forced aeration. In comparison with activated sludge plants, trickling filter plants require fewer operators and will have lower operating costs.

In determining the circumstances under which synthetic media trickling filters should be chosen over other alternatives, the major decision factors are cost-effectiveness, performance reliability, energy requirements, operating skill, and land needs. These factors should be weighed in terms of the needs of the individual installation. In general, plastic-media filters should be selected under any one of the following conditions:

1. Existing rock filters need renovation.

2. Partial removal of BOD_5 is needed preceding another secondary treatment unit.

3. The most important criterion is minimizing energy use.

METRIC CONVERSION FACTORS

1 in. = 25.4 mm
1 ft = .3048 m
1 sq ft = .0929 m^2
1 cu ft = .0283 m^3
1 lb = .4536 Kg
1 gal = 3.785 L
1 acre-ft = 1233 m^3
1 gpm = .00006309 m^3/S
1 gpd = .0037854 m^3/d
1 mgad = .9354 m^3/m^2 d
1 cfm = .00047195 m^3/S

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